



Current and Emerging Resource Issues

This chapter discusses current and emerging natural resource issues that will need to be addressed in the future. Topics such as climate change, invasive species, aquatic resource issues, deer impacts, and biofuels are considered. This information should also be considered when developing resource and land use plans statewide and when managing for the long term.

Climate Change

Climate change research and modeling have indicated that a changing world climate could have important impacts on all of Wisconsin's vegetation and aquatic features. The Wisconsin Initiative on Climate Change Impacts (WICCI), a statewide collaboration that brings scientists and stakeholders together to find adaptation strategies to the potential impacts of climate change in Wisconsin, has been instrumental in coordinating the work of scientists summarizing Wisconsin's historical climate data and localizing global climate projections to Wisconsin under different carbon emission scenarios and climate models (WICCI 2010b) (for further information, see WICCI Working Group reports on the WICCI website, <http://www.wicci.wisc.edu/>). Spatially interpolated data from 176 weather stations measuring daily maximum and minimum temperatures and precipitation in and around Wisconsin indicate that over the time period from 1950 to 2006 Wisconsin's climate has become wetter in southern and western Wisconsin and dryer in the far northern part of the state. Average winter temperatures have shown the greatest increase, with northwest and central areas of the state warming by 3.5°F to 4.5°F. Average spring temperatures have increased by around 3°F in the northwestern part of Wisconsin and by 0.5°F to 2°F degrees in most of the rest of the state. Changes in spring *phenology*¹ have been documented and are an indicator that Wisconsin is experiencing climate change impacts (Bradley et al. 1999). The date of the last killing frost in spring has changed across much of the state and occurs approximately one week earlier now than it did in

1950, resulting in a longer growing season. In northwestern Wisconsin, it now occurs up to 18 days earlier than it did in 1950. Summer and autumn average temperatures have been relatively stable (Kucharik et al. 2010).

Importantly, the WICCI analysis of climate data indicates that changes in temperature and precipitation have varied spatially and temporally in Wisconsin since 1950 and that, while there were seasonal increases in mean temperatures, variability in temperatures has increased as well. This variability can create uncertainty as to the exact timing, location, and magnitude of future climate change impacts. Despite this uncertainty, current trends provide important information that can be used to make seasonal and regional predictions of future conditions.

WICCI scientists localized and adapted global climate models to make climate projections for our state in 2055 and 2090 (WICCI 2010a). The greatest warming is projected for wintertime average temperatures, and in northwest Wisconsin the average winter temperature could increase by 9°F to 11°F by 2055. Springtime average temperatures are projected to increase by 3°F to 9°F and autumn temperatures by 4°F to 10°F in the same time period. Summer averages are projected to change by 3°F to 8°F, with the greatest increases in the north central part of the state. Precipitation projections are less certain, and average precipitation could increase or decrease. Temperature extremes and the frequency of heavy precipitation events are projected to increase markedly.

Predicted Effects of Climate Change on Fish and Wildlife

Changes in climate will have different impacts on many different species of fish and wildlife. The WICCI Wildlife Working Group evaluated wildlife species likely to be vulnerable to climate change (WICCI 2010a). Impacts on wildlife due to climate change can be both direct and indirect (primarily through habitat change and interspecific interactions). Wild-

¹Terms highlighted in green are found in the glossary in Part 3 of the handbook ("Supporting Materials"). Naming conventions are described in Part 1 in the Introduction to the handbook. Data used and limitation of the data can be found in Appendix C, "Data Sources Used in the Handbook," in Part 3 of the handbook.

life are already subjected to stressors not related to climate change such as habitat fragmentation, invasive species, and pollution. These stressors are expected to continue and have **synergies** with climate change. Some wildlife species will do well under climate change; many will not. Species that have short generation times, are widely distributed, move easily across the landscape, have general habitat requirements, and are not sensitive to human activity will fare better; conversely, species that have long generation times, narrow distributions, poor dispersal ability, special habitat requirements, and are sensitive to human activity will fare poorly (McKinney and Lockwood 1999).

Altered snow cover and temperature, particularly in the extremes of northern Wisconsin, may challenge the survival of some mammalian wildlife (WICCI 2010a). Shallow snow cover and freezing rain in winter may reduce the thermal benefits of snow tunnels and cause some mammals to die from cold exposure or being exposed to predation. In Wisconsin, the American marten (*Martes americana*) is an example of a species that could be affected by climate change because it is at the southern extent of its range. An important limitation to marten distribution is adequate snow cover. The American marten often rests under snow-covered woody debris, permitting it to survive in northern climates (Buskirk et al. 1989). Because winter temperatures are projected to increase in the state, affecting snow conditions (both the density and depth of snow as well as the length of time snow covers the ground), inadequate protection from the cold may reduce the ability of the American marten to persist in Wisconsin (WICCI 2010a). In addition, the American marten's primary prey source, small mammal populations, may be reduced by exposure to the cold and increasing predation rates from other predators with less snow cover. Both of these factors may contribute to reducing American marten survival in Wisconsin.

The U.S. North American Bird Conservation Initiative (NABCI) and experts from the nation's leading conservation organizations and agencies released a report on expected changes to migratory birds due to climate change (State of the Birds 2010 Report on Climate Change; NABCI U.S. Committee 2010). The report shows that climate change will have an increasingly disruptive effect on bird species in all habitats. When vulnerability to climate change was predicted by habitat, almost half of grassland bird species and almost a third of wetland and forest bird species were predicted to have medium to high vulnerability to climate change. Many grassland birds may be at increased risk because of drought caused by higher evapotranspiration, even with increased rainfall in some areas. In addition, rainfall events are predicted to be more sporadic and severe. Important wintering areas for many grassland birds may become less suitable due to increased drought (e.g., less dense escape cover and reduced seed production and/or insect populations as a food source), invasive species, and invasion by woody plants in wetland areas. Increased drought conditions and higher

evapotranspiration rates may cause loss of wetlands, which could lead to significant reductions in wetland birds. Forest types in eastern states are predicted to shift northward and alter bird communities.

Amphibians are particularly sensitive to drought conditions because they have permeable skin and require waterbodies for reproduction (WICCI 2010a). Nineteen amphibians are native to Wisconsin, and six are of conservation concern. The northern cricket frog (*Acris crepitans*) is the only amphibian listed as Wisconsin Endangered. Once common in the upper Midwest, the species began a considerable regional decline in the late 1950s (Gray and Brown 2005). Although the exact cause remains unclear, periodic drought conditions over a period of several decades may be an important source of mortality (Hay 1998). Under more frequent drought conditions projected to increase in severity and spatial extent (IPCC 2007), local extinction is a possibility for many Wisconsin amphibians (WICCI 2010a).

Global climate change will cause Wisconsin streams and rivers to become warmer over the next 50 years, although the magnitude of the temperature increase is uncertain. Wisconsin is recognized for its abundance of coldwater streams, which includes over 10,000 miles of classified trout streams. Expected changes in precipitation patterns that affect hydrology and land use across Wisconsin due to global climate change may threaten the viability of Wisconsin's inland coldwater systems (Mitro et al. 2007). Stream temperature is the most important factor that determines where trout and other coldwater species can live. A warming climate will affect the



American marten. Photo by Edwin and Peggy Bauer, courtesy U.S. Fish and Wildlife Service.

distribution of trout and other coldwater species. Under the largest modeled water temperature increase of 3°C, these coldwater habitats are predicted to decline by 95%, whereas under the smallest modeled water temperature increase of 1°C, the decline will be about 50%. Extreme precipitation events associated with climate change may limit recruitment of trout and other coldwater species. Drought conditions associated with climate change will decrease stream flows, limit movements of aquatic species, and reduce habitat availability.

Some warmwater fishes, preferring summer water temperatures above 21°C, are likely to expand their distribution (Lyons 2007). Widespread warmwater species adapted for headwaters, such as creek chub (*Semotilus atromaculatus*), fathead minnow (*Pimephales promelas*), and johnny darter (*Etheostoma nigrum*), are expected to expand their distributions into most of the stream reaches that can no longer support coldwater communities (Lyons 2007). Less widely distributed headwater species, such as southern redbelly dace (*Phoxinus erythrogaster*), will show much smaller expansions because they will be prevented from accessing much of the former coldwater habitat by dams and unsuitable habitat (lakes, large rivers). Species preferring larger streams and rivers, including shorthead redhorse (*Moxostoma macrolepidotum*), smallmouth bass (*Micropterus dolomieu*), and logperch (*Percina caprodes*), will show little change in distribution. Under the largest projected temperature increase, some species, notably walleye (*Sander vitreus*), may decline in distribution as some large rivers become too warm for them. Although many Wisconsin warmwater stream species are predicted to have relatively little change in distribution from stream warming, climate change may nonetheless have major effects on their populations through milder winters, earlier spawning periods, expanded growing seasons, and changes in community dynamics (Lyons 2007).



Cricket frog (*Acris crepitans*) (Wisconsin Endangered) calling from stand of duckweed (*Lemna minor*) in a southwestern Wisconsin marsh. Photo by Rori Paloski, Wisconsin DNR.

How Can We Address Climate Change?

A question is sometimes posed as to whether society can or should try to plan for climate change, since there is considerable uncertainty about how much the global climate will change and how impacts will vary at local and regional scales. Change is unequivocal, and we are experiencing changes today, and more detrimental impacts are anticipated in the future with major implications for society (IPCC 2007). Carbon dioxide is a greenhouse gas that is stable in the atmosphere for decades to thousands of years, so effects of the amount of carbon dioxide already accumulated in the atmosphere will be felt for hundreds of years, even if emissions are slowed or stopped today.

Still, there are actions we can take right now to help reduce the magnitude of climate change and adapt to its impacts. Mitigation strategies that seek to sequester carbon or reduce greenhouse gas emissions can help reduce or delay climate change impacts. Adaptation strategies, such as protecting highly valued resources or improving the capacity of an ecosystem to return to desired conditions following disturbance, can reduce an ecosystem's vulnerability to the negative impacts of climate change. We can also work toward adapting to the climate change that is inevitable by preserving the resiliency of ecosystems and keeping as many of our options open as possible.

To address climate change, we need to plan regionally and locally to ensure there is a diversity of plants and animals across the state that can adapt to climate change. We should emphasize adaptive resource management practices that preserve and enhance maximum genetic, species, natural community, and ecosystem diversity. It will be important to maintain as many representative natural communities as possible, preserve connectivity of habitats, and develop corridors that will allow plants and animals to disperse. As conditions change, it may not be possible to maintain some natural communities in their present condition except via very intensive management. An important challenge for managers will be recognizing change and adapting management practices to new conditions and realities. Some goals will need reassessment, and innovative conservation design may be required.

The Wisconsin DNR and the Michigan Department of Natural Resources and Environment took one step in implementing an overall climate change strategy in 2010. They signed a Memorandum of Understanding to establish common goals and jointly pursue research, planning, and implementation focused on climate change. Common goals include protecting the health and integrity of our natural ecosystems and human population through the wise stewardship of our natural and cultural resources. Both states intend to invite other states into a multi-state cooperative to help the Great Lakes region address climate change. They plan to identify and communicate opportunities for joint participation in projects and programs of mutual interest.

and share the results of research to maximize capability and limit duplication of effort. The states will propose action and potential funding options for greenhouse gas mitigation and climate change adaptation.

Things We Can Do to Mitigate Climate Change

Reduce Carbon Footprints

Reducing carbon dioxide emissions may mitigate climate change from becoming even more severe. Many scientists believe that a safe threshold of carbon dioxide accumulation in the atmosphere has already been exceeded and that it is critical to reduce atmospheric CO₂ concentrations immediately to avoid even more serious consequences than the ones that have already been set in place (Hansen et al. 2008). Practicing energy conservation may be the best way that society can rapidly mitigate climate change. Measures that can be taken within a government agency include using energy saving devices, renewable energy sources, and ways of doing business that are less fossil fuel dependent (e.g., using LiveMeeting rather than traveling to distant sites for meetings). In addition, promoting recreation that uses less fossil fuel, such as hiking, biking, bird watching, cross-country skiing, or canoeing, may be more beneficial than promoting additional snowmobile and ATV trails, which will increase fossil fuel use.

Natural Resources Management

Natural resources can be managed to sequester and store more carbon. Removing CO₂ from the atmosphere is an immediate priority, and one way to accomplish this is by encouraging the growth of plants that accumulate carbon in their tissues. Some plants accumulate more carbon than others, and woody plants and deeply rooted prairie species are among them. However, when these plants are harvested, much of the carbon is again released to the atmosphere, so the cycle of harvesting and the timing of carbon release is an important consideration.

Reforestation of some lands in appropriate places could sequester more carbon. However, old forests should not be cut and replaced with young, fast-growing forests for carbon management. Even though the rate of carbon sequestration is more rapid in young forests, the release of stored carbon to the atmosphere from the removal of the old forest may take 200 years to recover (Harmon et al. 1990). When considering reforestation, a balance between sequestering carbon and preserving natural diversity is needed; diversity must be maintained so ecosystems can adapt to climate change. Reforestation should be undertaken where it can provide ecological value (e.g., establish forested corridors that allow plants and animals to disperse or provide critical habitat for rare species) in addition to carbon sequestration and storage. For example, reforesting areas along the Lake Michigan coastline in the Central Lake Michigan Coastal and Northern

Lake Michigan Coastal ecological landscapes may not only sequester carbon but also provide dispersal corridors for plants and animals and critical migration habitat for migratory birds. Reforestation in the Forest Transition Ecological Landscape could sequester carbon as well as provide dispersal corridors between southern and northern Wisconsin. Places where reforestation would be inappropriate would be in grassland or barrens management areas because this would harm the diversity and functionality of these ecosystems. In these areas, prairie and barrens restorations and surrogate grasslands should be used to sequester carbon as well as provide important habitat for grassland and barrens species.

Reduce and Avoid Loss from Existing Carbon Stores

Communities that currently store considerable amounts of carbon, including peatlands and old-growth forests, should be protected to maintain the carbon stores. Additional lands could be managed for old growth forests to help mitigate climate change. Converting these communities to alternative land uses, such as agriculture and residential development, releases stored carbon. Even if the goal of the alternative land use is to sequester carbon or produce renewable energy or biofuels, the release of stored carbon and the energy required to convert to alternative land uses creates a carbon debt that can take decades to centuries to overcome (Fargione et al. 2008).

Renewable Energy

Use of biomass from forest products residue, whole tree harvesting, switchgrass, and other sources might be used to generate renewable energy. However, these practices need to be considered carefully for their net energy balances, potential for net CO₂ emissions to the atmosphere, appropriateness of the location within the state, soil nutrient depletion, resulting habitat changes (particularly structure), and social aspects such as job creation or loss. (See the “Bioenergy” section in this chapter.)

Use of fast growing trees and native grasses might be considered as a renewable energy source. However, one of the first steps that should be taken is to calculate how much carbon a given land management practice can sequester and how much land it will take to make it worthwhile. In addition, the value of the current land use that would be displaced should be considered (e.g., replacing an old growth forest that supports rare species with a younger forest plantation or disturbing old grassy fields that are already sequestering carbon). Social needs should also be considered, such as the use of water to irrigate biofuel plantations rather than using it for drinking water or the use of land for the production of biofuels rather than food for people.

The total carbon savings should be calculated over the lifespan of the practice to make sure that more carbon is sequestered than used in the process. For example, if trees are planted to sequester carbon, the entire carbon budget of

planting, growing, harvesting, transporting, and processing needs to be considered in the net carbon budget.

Where biofuels are grown will be of ecological importance. Plantations of trees in grassland and/or barrens management areas could harm the ecology of the area, making it difficult for grassland and barrens species to survive. On the other hand, if tree plantations are located in forest openings or adjacent to forested areas, they could enhance the ecological function of the area by providing buffers to lands already forested. The same is true for grassland bioenergy crops. They should not be located in forested areas but rather in areas that were or are now primarily grasslands.

Things We Can Do to Adapt to Climate Change

Adaptive resource management strategies should be employed to help ecosystems adjust to changing conditions. Despite model projections, we do not know with certainty how ecosystems will respond to climate change. Adaptive resource management will be a key strategy to deal with the unforeseen changes that are sure to occur. A useful review of recommendations for the management of biodiversity within a context of climate change has been published recently in the journal *Biological Conservation* (Heller and Zavaleta 2009). The factors highlighted and briefly discussed below were among a subset that appeared most frequently in the recommendation made by researchers working on this topic over the past 22 years.

Protect Native Communities

Preserving and managing native habitats, communities, aquatic features, and landscape complexes at a variety of scales needed to support associated species, structures, and natural processes may allow these ecosystems to more easily adapt to climate change. Highly disturbed ecosystems may be less able to adapt to climate change, especially if they have been greatly simplified and occur in landscapes characterized by severe fragmentation. Maintaining the highest possible diversity of native habitats, natural communities, and landscapes across the state (as well as high genetic diversity among the native plants and animals present) will be a critical adaptation strategy. It should allow some species to disperse or adapt to changing climates. New assemblages of plants and animals may develop in the future as a result of environmental change, including climate change, but accommodating the greatest number of native habitats and species may also provide for the greatest number of viable options in the future. The maintenance of natural communities and aquatic reference areas may also provide “benchmarks” against which to measure the effects of climate change.

Reduce Human-Caused Stressors

Human-caused stressors should be reduced as much as possible, such as pollutants and toxins, land uses that stress or

compromise natural communities, and invasive species that replace native plants and animals. By preserving as much natural diversity and ecosystem function as possible, we can maintain more options for allowing ecosystems to adapt to a changing climate.

Climate change could exacerbate impacts from other current major stressors on natural resources, such as invasive species, hydrological disruption, land use changes, human population growth or significant shifts in human populations, and high densities of white-tailed deer (*Odocoileus virginianus*). In addition, the impacts these stressors are having now could reduce the extent, diversity, and functionality of native ecosystems, making it difficult for them to adapt to climate change.

Maintain Dispersal and Migration Corridors

Although some species may not be able to disperse fast enough to adapt to a changing climate, maintaining corridors of suitable habitat will make dispersal a more likely possibility. Corridors connecting northern and southern Wisconsin may be especially important. Large rivers and their floodplains are often good candidates for dispersal corridors because most large rivers run from northern to southern Wisconsin, and many of them have associated habitats that can support dispersal. Maintaining and enhancing habitat along these river systems may be important to facilitate dispersal of both aquatic and terrestrial species as they adapt to climate change by moving. Where feasible, linking public lands may be the most efficient way to develop corridors. For example, maintaining or restoring undeveloped, continuous corridors of riparian habitats (including forests, various wetland communities, and aquatic habitats) along the Black River could link or come close to linking the Chequamegon-Nicolet National Forest, Black River State Forest, Big Creek Fishery Area, North Bend Bottoms State Wildlife Area, Van Loon State Wildlife Area, and the Upper Mississippi River National Wildlife and Fish Refuge. A critical factor needed to achieve success is to increase coordination and cooperation among landowners and managers, which, in some, if not most, cases will mean that jurisdictional obstacles will need to be overcome.

For other habitats, such as open grassland or savanna ecosystems, corridors might be created along utility corridors or other rights-of-way, or the management of forested areas now separating areas between open habitats might be designed so that they are at least periodically connected.

Relationship of This Handbook to Climate Change

The information in this handbook provides a baseline from which the impacts of climate change may be projected and measured and upon which adaptive strategies might be planned. Ecological landscapes described in this handbook are based on the National Hierarchical Framework of Eco-

logical Units (Cleland et al. 1997), which allows the flexibility of working at multiple scales. Ecological landscape delineations are based on similarities of climate, geology, soils, vegetation, land use, and management opportunities. Therefore they may provide an effective framework through which to consider the effects of climate change.

Ecological landscapes may be used for projections of vegetation change under future climates. Native vegetation that currently exists within each ecological landscape and why the physical environment supports this vegetation are detailed in this handbook and should help project what vegetation may exist there under different climate scenarios. The Minnesota DNR has projected vegetative cover that might exist in different ecoregions of their state under different climate scenarios (Carstensen et al. 2008). Similar research is underway at the University of Wisconsin-Madison using forest process modeling along with paleoecological information from past climate change and vegetation responses, to predict vegetation responses under future climate scenarios (Objectives of this project can be found in Hotchkiss and Mladenoff 2007). The product from this study will provide projected vegetative cover in different ecoregions of Wisconsin under different climate scenarios.

The Chequamegon-Nicolet National Forest Climate Change Response Framework will incorporate landscape management activities that will help adapt forests to new and changing conditions as well as mitigate greenhouse gas emissions responsible for climate change. This project will provide guidance on rapidly incorporating science and monitoring information into Chequamegon-Nicolet National Forest management activities to mitigate carbon emissions and better adapt ecosystems to changing climate.

Appendix E, "Opportunities for Sustaining Natural Communities in Each Ecological Landscape," in Part 3 of the handbook ("Supporting Materials"), shows locations in Wisconsin that are the best ecological landscapes in which to manage these ecological features, selected habitats, and aquatic features. A table of ecological opportunities for projected future habitats due to climate change could be developed for each ecological landscape. Although it is unlikely that natural communities will be composed of the same species in the future and move as entire single units, this table would be useful in predicting where natural communities may occur in the future and how best to plan for their management. The new projected information where different habitats may occur under climate change should be useful for developing adaptive strategies to manage natural resources that conform to future climates.

Wildlife species' presence and abundance are related to habitat requirements. Once the analysis suggested above has projected where future habitats are likely to occur, wildlife habitat relationships could be used to project what wildlife species might occur in different parts of the state in the future. Wildlife adaptive strategies could then be developed for the wildlife of the state.

Invasive Species

For the purposes of this handbook, invasive species are defined as nonnative plants, animals, and pathogens that cause or are likely to cause economic or environmental harm or harm to human health (NR 40, Wis. Adm. Code; Wisconsin DNR 2009a). Invasive species have spread to a wide range of terrestrial and aquatic ecosystems and now rank just behind habitat loss as the leading cause of rare species declines in the U.S. (Wilcove et al. 1998). As with most parts of the world, invasive species are a serious threat to Wisconsin's ecosystems. They threaten biodiversity through the loss and alteration of native species habitats, and they can limit the ability to sustain production of natural resources such as timber and agricultural crops.

Wisconsin invasive species are usually not native to the areas they invade; they often are not native to North America. However, native species can become invasive due to ecosystem disruption, fragmentation, and further ecosystem simplification caused by habitat alterations or modifications of historical disturbance regimes. Once ecosystems are disrupted, some native species can outcompete or negatively impact native communities. Examples of native species that can become invasive include common prickly-ash (*Zanthoxylum americanum*), red-osier dogwood (*Cornus stolonifera*), sumacs (*Rhus* spp.), river bank grape (*Vitis riparia*), and Virginia creeper (*Parthenocissus quinquefolia*) (Czarapata 2005). These species can outcompete other native plants and result in community simplification under disturbed conditions. In addition, other native species can defoliate trees or cause disease that affect forest ecosystems by causing widespread tree mortality. Examples of native species that can affect forest ecosystems include the forest tent caterpillar (*Malacosoma disstria*) and the fungus that causes Annosum root rot (*Heterobasidion annosum*).

History of Invasive Species

Early settlers brought domestic livestock and European plants to the Midwest for food and medicine. Along with these crops came unintended weed seeds and animal pests that later became established here. Nonnative species have been introduced for agricultural crops, forage for livestock, and for recreation. In addition, invasive species such as reed canary grass (*Phalaris arundinacea*) and crown-vetch (*Coronilla varia*) have been introduced for erosion control, and Japanese barberry (*Berberis thunbergii*), purple loosestrife (*Lythrum salicaria*), and earthworms (Acanthodrilidae, Lumbricidae, Megascotocidae families) have been introduced for gardening. Norway maple (*Acer platanoides*) has been introduced as a shade tree, and Gypsy moth (*Lymantria dispar*) has been introduced for silk production. Common carp (*Cyprinus carpio*), brown trout (*Salmo trutta*), rainbow trout (*Oncorhynchus mykiss*), and Chinook salmon (*Oncorhynchus tshawytscha*) have been introduced for sport

fishing while the Ring-necked Pheasant (*Phasianus colchicus*) and Gray Partridge (*Perdix perdix*) were introduced as game animals (Wisconsin Council on Forestry 2009). See Kearns (2008) for a detailed description of the history of invasive plants in Wisconsin.

Nonnative species have continued to be introduced unintentionally, and with the rise in globalization, species from anywhere in the world can now enter the state as we import raw materials from other countries. Untreated solid wood packing material and firewood are pathways through which nonnative insects have reached our forests. Ships entering the Great Lakes from foreign waters have introduced nonnative aquatic species such as ruffe (*Gymnocephalus cernuus*), a Eurasian fish, and zebra mussel (*Dreissena polymorpha*) by dumping their ballast water at Great Lakes ports. Most earthworm species in Wisconsin were introduced from Europe in potted plants (Kearns 2008). The pet and aquarium trade has also resulted in unwanted exotic pets (e.g., fish and animals) being released into the wild, which sometimes establish unwanted breeding populations.

Humans can further spread invasive species from the point of introduction via mowers, all-terrain vehicles, logging trucks, tractor trailers, campers, boats, and pets as well as hay and other livestock feed, seeds, gravel, soil, mulch, firewood, lumber, packing crates, and live plants. Livestock, horses, and humans can also spread invasives (Kearns 2008). Certain earthworms popular for composting and gardening have been distributed to new areas by well-intentioned gardeners. Also, earthworms and other animals such as the rusty crayfish (*Orconectes rusticus*) have been distributed by fisherman when discarded as unused bait.

Some nonnative species are relatively harmless because they do not reproduce or displace native species in their new surroundings. However, others greatly expand in new areas because they can establish populations very quickly, thrive in a wide range of environmental conditions, are often easily dispersed, and are not limited by the factors such as diseases, predators, parasites, and/or abiotic conditions that kept their populations contained in their native range. These species can become aggressive and harm the economy, ecology, or human health in their new environments.

Today there are thousands of nonnative species in Wisconsin, including over 800 nonnative plant species (27% of the current flora) (Kearns 2008). Fortunately, populations of most of these species are small and of little ecological concern. However, 35 invasive plant species are of serious concern, another 148 are considered locally invasive (Kearns 2008), and several other species have the potential to become serious problems in the future.

Nonnative terrestrial animal species that have established breeding populations in Wisconsin include feral domestic cats and hogs, the Mute Swan (*Cygnus olor*), Rock Dove (*Columba livia*), European Starling (*Sturnus vulgaris*), House Sparrow (*Passer domesticus*), and several other species. In 2007 the Great Lakes alone had 180 nonindigenous

aquatic species with reproducing populations (GLANSIS 2010); these can be spread via moving water and equipment to surrounding inland lakes and rivers.

Effects of Invasive Species

Invasive species can replace native species, alter the ecological relationships among native species, negatively impact ecosystem function and structure, decrease the economic value of ecosystems, and threaten human health. They pose worldwide threats to habitats and economies in areas as diverse as agriculture, forestry, livestock, fisheries, and recreation. Nonnative “weeds” cost private citizens and agencies billions of dollars in North America every year. It is



Mesic forest with diverse understory and displaying a carpet of several “spring ephemeral” plant species. Photo by Ryan O'Connor, Wisconsin DNR.



Northern Mesic Forest in Lincoln County, impacted by nonnative earthworms. Five years prior to this photo, this area supported abundant herbaceous species. In addition to the European earthworm species known from Wisconsin, several Asian species are now found in the Great Lakes region and could present a major threat to Wisconsin forests. Photo by Joe Kovach.

estimated that the cost of controlling these plants, combined with the economic loss to our rangelands, crop fields, waterways, and forests, approaches \$35 billion annually in the United States alone (IPAW 2010).

Invasive insects and disease-causing microorganisms have had highly detrimental effects to Wisconsin forests, such as white pine blister rust (caused by the fungus *Cronartium ribicola*) and butternut canker (caused by the fungus *Sirococcus clavigignenti-juglandacearum*) (see McCullough and Zablotny 2002 and Wisconsin Council on Forestry 2009). The decline of native elms (*Ulmus americana*, *U. rubra*, *U. thomasi*) illustrates the damage that can be caused by an introduced pathogen such as Dutch elm disease, which is caused by the fungus *Ophiostoma ulmi* and spread by two beetle species, a native elm bark beetle, *Hylurgopinus rufipes*, and an introduced European beetle, *Scolytus multistriatus*. Elms were once major components of eastern U.S. hardwood forests and were planted as shade trees in eastern U.S. cities. In the 1930s, the Asian fungus that causes Dutch elm disease was introduced into North America from imported European logs, and by 1980 it had killed the majority of mature elm trees in the state (Wisconsin Council on Forestry 2009).

Native ashes (*Fraxinus* spp.) are being eliminated from some forest communities by the emerald ash borer (*Agilus planipennis*). Infestations of this nonnative beetle in North America were first reported in Michigan in 2002, where it is believed to have killed more than 30 million trees (USFS et al. 2010). The emerald ash borer has since been found in Canada, Ohio, Indiana, Illinois, Pennsylvania, Missouri, Wisconsin, Maryland, West Virginia, Virginia, Kentucky, New York, and Minnesota. The economic scope of this problem could reach billions of dollars nationwide, and state and federal agencies have made slowing the spread of the emerald ash borer a priority.

Beech bark disease, a major threat to American beech (*Fagus grandifolia*), is the result of an interaction between a nonnative scale insect (*Cryptococcus fagisuga*) and fungi (*Neonectria* spp.), and only occurs when both are present. It is spreading through the Upper and Lower Peninsulas of Michigan and eastern Wisconsin, although the number of affected trees is low outside of Door County (Wisconsin DNR 2013). This disease could eliminate beech from the state. Other important tree species in Wisconsin such as eastern hemlock (*Tsuga canadensis*), spruces (*Picea* spp.), oaks (*Quercus* spp.), and maples (*Acer* spp.) could be affected by invasive insects and diseases that are already established in other states (Kearns 2008).

Nonnative shrubs are among the most common invasive species in Wisconsin. Eurasian buckthorns (*Rhamnus cathartica* and *R. frangula*) spread aggressively, forming dense thickets that negatively impact the establishment of tree seedlings (Frappier et al. 2003, 2004). Nonnative honeysuckles (especially *Lonicera tatarica* and the hybrid *Lonicera x bella* but also *L. mackii* and *L. morrowii*) also grow in dense thickets and spread rapidly. Honeysuckle invasions prevent

tree seedling establishment and reduce the abundance, richness, and density of tree seedlings in forest communities (Woods 1993, Hutchinson and Vankat 1997, Collier et al. 2002). Several native shrubs may increase explosively and become management problems under disturbance regimes such as heavy grazing or severe logging. Native shrubs that can do this include common prickly-ash, several gooseberries (*Ribes* spp.), and brambles (*Rubus* spp.).

There are many invasive herbs. Over 40 of the 66 invasive plants on the Invasive Plants Association of Wisconsin's (IPAW) working list in 2003 were herbaceous species (IPAW 2003), all of them nonnative. For example, reed canary grass is considered to be the most extensive wetland plant invader in Wisconsin. A landscape-level assessment in 2008 showed that this species has replaced many native species and is now dominant in 26% of emergent wetlands and almost 10% of all wetlands in the state (Hatch and Bernthal 2008). Garlic mustard (*Alliaria petiolata*) is an invasive plant that invades forests, even undisturbed sites (Stinson et al. 2006), replacing native vegetation and even suppressing tree regeneration. Tree regeneration is affected when garlic mustard disrupts beneficial associations between tree seedling roots and fungi (*mycorrhizal associations*). There are many other examples of invasive herbaceous plants. See the 16 ecological landscape chapters for information on which invasive species are among the important management problems in each ecological landscape.

Nonnative earthworms alter the chemistry and structure of forest soils, reduce the organic matter in the upper layers of the soil, impact tree regeneration and growth, and change the forest floor plant composition (Bohlen et al. 2004). These changes likely impact many other parts of the forest ecosystem, such as ground-nesting birds (Fox et al. 2010).



Oak savanna restoration with a severe oriental bittersweet (*Celastrus orbiculata*) infestation in Walworth County. This species, often planted as an ornamental but now under legal restrictions in Wisconsin, has the ability to girdle trees and weigh down their crowns, in addition to shading out understory plants. Photo by Ryan O'Connor, Wisconsin DNR.

Numerous invasive species currently impact aquatic ecosystems. As an example, the common carp was introduced as a sport and food fish in the 1880s and has invaded many inland waters in southern and central Wisconsin. Its habit of uprooting aquatic vegetation as it feeds on the bottom stirs up sediments, greatly increasing the turbidity and nutrient levels of many rivers, lakes, and marshes. The common carp's activities can prevent native aquatic plants from growing, making it difficult for other aquatic animals to find food and shelter. Millions of dollars have been spent trying to control the common carp in Wisconsin. Other serious invasive species in aquatic ecosystems include purple loosestrife, common reed (*Phragmites australis*), reed canary grass, Eurasian water-milfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potamogeton crispus*), sea lamprey (*Petromyzon marinus*), rainbow smelt (*Osmerus mordax*),

alewife (*Alosa pseudoharengus*), rusty crayfish, spiny water flea (*Bythotrephes cederstroemi*), zebra mussel, and quagga mussel (*Dreissena rostriformis*). Many more species pose threats for the future.

Managing Invasive Species

Managing invasive species is difficult because they are often widespread and well established before they are recognized as a problem. Some insects or fungi are so small that their populations go unnoticed for many years. Other species can be noninvasive initially but later become a problem due to adaptation; hybridization such as happened with narrow-leaved cat-tail (*Typha angustifolia*); movement to more favorable habitats by wildlife and humans as occurs with multiflora rose (*Rosa multiflora*) or buckthorn; creation of open disturbed areas favorable for rapid colonization; or the population reaching the size where exponential growth occurs. Once an invasive species reaches the exponential growth stage, it is very difficult to control and virtually impossible to eliminate. Detecting invasive species when they are first invading an area makes control efforts more effective and cost efficient (Wisconsin DNR 2009b). The Wisconsin DNR's invasive species web pages include a list of target plant species that, although not yet present, have been included because of their potential for invasiveness in Wisconsin.

One feature common among many invasive species is the role that human activities play in contributing to their introduction and spread. Changing the behavior of citizens could make a difference in the future introduction and spread of invasive species (Vander Zanden and Maxted 2008). Preventing the introduction or movement of invasive species, as well as controlling them once they are established, must be part of any management planning effort in the state. For example, it is now well understood that transporting firewood is probably the biggest risk factor in creating new infestations of the emerald ash borer. Land managers may need to modify their maintenance and management activities since areas with high human use (e.g., roads, right-of-ways, trails) are a source from which invasive species often spread.

The Wisconsin DNR has a very active invasive species management program designed to take advantage of a large body of research, decrease the time before a species is detected, and respond to outbreaks quickly (Wisconsin DNR 2010a). Integrated resource management will be needed to prevent and control the spread of invasive species across the state. Integrated resource management includes preventing the introduction of invasive species, an awareness of invasive species that could become a problem, early detection of invasive species, inventory and mapping of invasive species, control and monitoring of existing invasive species populations, and research to develop control techniques for invasive species. Sources of information on invasive species identification and control can be found on



Field completely dominated by reed canary grass to the exclusion of virtually all other plants. This species is particularly problematic in wetlands and has been planted for decades as livestock forage and erosion control. Photo by Elizabeth J. Czarapata.



Area with the groundlayer completely dominated by garlic mustard, a major threat that has become increasingly dominant on many state-managed lands, especially in southern and central Wisconsin. Photo taken in a state park in Sauk County. Photo by Eric Epstein, Wisconsin DNR.

the Wisconsin DNR website, <http://dnr.wi.gov/>, keyword “invasive species.” Also, for information on invasive species that threaten specific ecological landscapes, see the 16 ecological landscape chapters.

Biological control agents are often the only feasible tool for reducing the impacts caused by widespread invasive species. An extensive research and testing process is designed to reduce the risks associated with introducing additional nonnative species. Several biological controls have been released in Wisconsin for invasive species. Two leaf-feeding beetles (*Galerucella pusilla* and *G. californiensis*), one root-boring weevil (*Hylobius transversovittatus*) and one flower-feeding weevil (*Nanophyes marmoratus*) from Europe have been released to control purple loosestrife in Wisconsin and have been relatively successful in reducing the dominance of purple loosestrife in marshes once beetles have become adequately established (Blossey and Schat 1997). Widespread and significant mortality to the gypsy moth larval stage has been documented as a result of two biological control agents (*Entomophaga maimaiga*), a fungus, and *Nucleopolyhedrosis* virus (NPV), although success varies based on conditions. However, other biological control measures for gypsy moth (spraying with BT [*Bacillus thuringiensis*]) are routinely

employed in stands with heavy outbreaks. Biological control of spotted knapweed (*Centaurea biebersteinii*) and leafy spurge (*Euphorbia esula*) began in 1991 and is currently being expanded to impact a larger portion of the state (Figure 5.1). Finally, three insects from Switzerland, including two stem miners, *Ceutorhynchus alliariae* and *C. roberti*, and a root and crown miner, *C. scrobicollis* have been identified and tested for controlling garlic mustard, and research on mass rearing of the biological control insects is in progress. Research on biological controls for a number of other invasive species is underway.

The Wisconsin Council on Forestry created the Forestry Invasives Leadership Team to develop voluntary best management practices (BMPs) to help control the spread of invasive species. Four sets of BMPs for invasive species were developed and are available (Wisconsin Council on Forestry 2009):

- Forestry BMPs
- Recreational Forest User BMPs
- Urban Forestry BMPs
- Transportation and Utility Rights-of-way BMPs

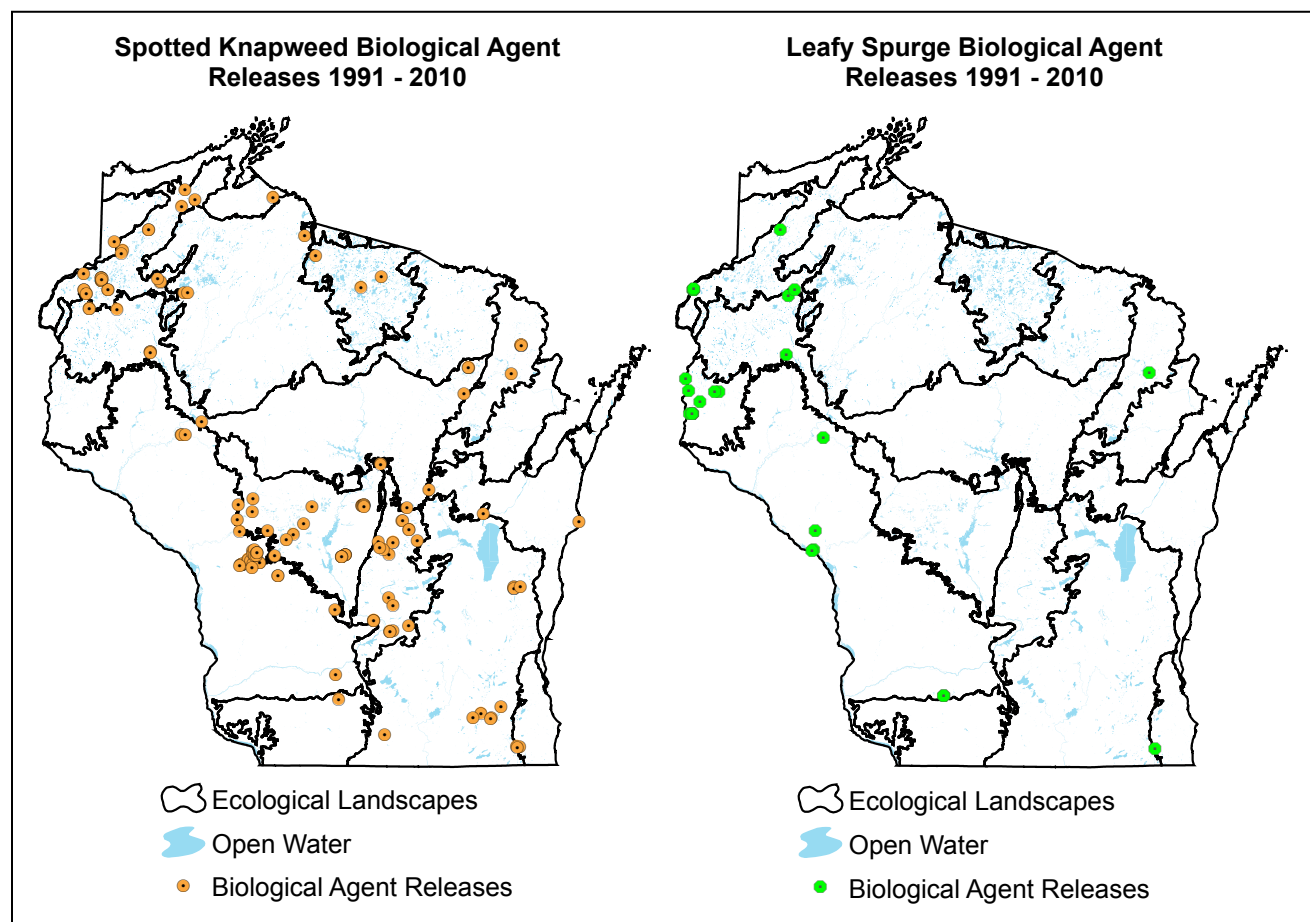


Figure 5.1. Wisconsin DNR priority biological agent release sites for spotted knapweed and leafy spurge, 1991–2010.

In September 2009, the Wisconsin state legislature directed the Wisconsin DNR to establish a statewide program to control invasive species and to promulgate rules to identify, classify, and control invasive species. Chapter NR 40 (Wis. Adm. Code), Wisconsin's Invasive Species Identification, Classification, and Control Rule (Wisconsin DNR 2009a), helps citizens identify and minimize the spread of plants, animals, and diseases that can invade our lands and waters and cause significant damage. A list of invasive species regulated by NR 40 can be found in Appendix 5.A at the end of the chapter.

As part of NR 40, citizens are required to take preventive measures to avoid spreading invasive species. The following are some of the requirements for citizens regarding aquatic invasive species:

- Remove all attached aquatic plants and aquatic animals from vehicles, boats, trailers, equipment, and gear of any type immediately upon their removal from the water.
- Drain all water from any vehicle, equipment other than boating or fishing equipment, or gear of any type immediately upon its removal from the water.
- Do not use a prohibited invasive fish or crayfish species as bait.
- Do not introduce a nonnative aquatic plant, algae, or cyanobacteria species into any water of the state.

Aquatic Resource Issues

There are a large number of current and emerging issues in water resources management that are intertwined with ecosystem management. Some ongoing issues, such as aquatic invasive species, agricultural runoff, and urban storm water, have been important management priorities for decades. Others, such as pollutant trading and total maximum daily loads (TMDLs) of pollutants, are relatively recent. The issues presented here are those that have the greatest impact on or connection to ecosystem management. Most are, or will be, topics in biannual reports prepared by the Wisconsin DNR Watershed Management program. Consult these reports for more details and future updates on these issues (Wisconsin DNR 2012b).

Watershed and ecosystem management approaches are emerging as the holistic framework in which ongoing and future watershed management issues will be addressed. These approaches integrate programs within a common framework around natural resource issues, all of which are interrelated. It is increasingly apparent that meaningful environmental and resource protection cannot be obtained by focusing on just one problem, like groundwater pollution, or by focusing on just one area of a watershed. Each resource problem and each problem area within a given watershed is related to the environmental, economic, and human health of a whole watershed.

Current Aquatic Resource Issues

Management of Wisconsin's aquatic ecosystems is affected by a host of both longstanding and relatively new resource management issues. Wisconsin's waters of the Great Lakes are influenced by the impacts of invasive species, the desires of shoreline residents to maintain or restore a high quality lake system, and the impacts of human population growth—often within the context of shared management decisions made with other states and provinces. The ecosystems of inland lakes and streams are influenced by increasing levels of shoreline development, continued inputs of point and nonpoint source pollutants, invasive species, and the presence of dams and other structures that can fragment stream habitat and alter stream function.

Great Lakes Issues

Ecosystem management in the Great Lakes basin is affected by issues related to international trade, population growth, and the need to involve Great Lakes states and provincial governments and the U.S. and Canadian federal governments in the management of interstate and international waters. Multi-institutional frameworks are in place to tackle a large array of problems and opportunities.

Great Lakes Strategy

Based on the priorities established by the Council of Great Lakes Governors, the Great Lakes Regional Collaboration brought together a unique partnership of federal, state, and local governments, tribes, and other stakeholders to develop goals and strategies to address the most pressing problems facing these world class resources. With the help of many stakeholders in the state, the Wisconsin DNR Office of the Great Lakes developed a parallel Great Lakes strategy for Wisconsin that provides state-specific actions to address the many issues facing Lakes Michigan and Superior. The latest update acknowledges the impacts of climate change on these resources and calls for incorporating adaptive planning and decision making in our daily activities.

This Wisconsin Great Lakes Restoration and Protection Strategy includes the following priorities:

- Ensure the sustainable use of our water resources consistent with states and provincial authority over water use and diversion of Great Lakes waters
- Stop the introduction and spread of nonnative aquatic invasive plants and animals
- Enhance fish and wildlife populations by restoring and protecting wetlands, rivers, streams, and associated uplands
- Promote programs to protect human health against adverse effects of pollution in the Great Lakes ecosystem
- Restore to environmental health the Areas of Concern (AOCs) identified by the *International Joint Commission* as needing remediation and restore other contaminated sediment sites in the Great Lakes Basin

- Control pollution from diffuse sources into water, land, and air
- Continue efforts to eliminate the introduction of *persistent bioaccumulative toxins (PBTs)* into the Great Lakes ecosystem
- Adopt sustainable use practices that protect environmental resources and enhance the recreational and commercial value of the Great Lakes
- Standardize and improve the methods by which information is collected, recorded, and shared within the region

Great Lakes Restoration Initiative

The U.S. Environmental Protection Agency (EPA) established a Great Lakes Restoration Initiative (GLRI) to address some of the more pressing problems in the Great Lakes. EPA has developed an Action Plan for 2010 through 2014. It was developed by 16 federal agencies as part of a federal inter-agency task force chaired by the EPA administrator. This plan will help guide the federal and state partnership efforts to implement the GLRI to restore and protect this natural and economic resource.

The plan directs aggressive action under five priority “focus areas” that the task force has identified as vital for restoring the Great Lakes:

- Protecting and cleaning up the most polluted areas in the lakes
- Combating invasive species
- Protecting high priority watersheds and reduction of runoff from urban, suburban, and agricultural sources
- Restoring wetlands and other habitats
- Implementing accountability measures, learning initiatives, outreach, and strategic partnerships

Great Lakes Compact

The Great Lakes Basin Compact is a formal agreement between the Great Lake states of Illinois, Indiana, Michigan, Minnesota, New York, Ohio, Pennsylvania, and Wisconsin. A parallel agreement includes the two Canadian provinces of Ontario and Quebec, which border the Great Lakes and St. Lawrence Seaway. In these agreements, the states and provinces agree to manage the water in the Great Lakes watershed collectively. This is, in part, intended to prevent the exportation of large quantities of Great Lakes water that could diminish habitat values in the open waters and critical estuarine areas of the Great Lakes. The agreements ban Great Lakes water from being “diverted,” or piped out of the Great Lakes Basins, with a few limited and strictly regulated exceptions. The Great Lakes Basin Compact became effective on December 8, 2008, after final consent from the U.S. Congress. The ban on the new or expanded diversions of water out of the Great Lakes basins (with exceptions possible for taking

drinking water for communities straddling the basin divide and approved by all compact signatories) began on this date. It requires each of the Great Lakes states to develop a water management program for the Great Lakes within five years using the elements required by the Compact. Wisconsin legislation implementing the Compact was enacted in 2008, and Wisconsin had its required management program fully in place by the end of 2011 (CGLG 2011).

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Pollution Prevention and Sediment Removal

Urban streams such as the Kinnickinnic River in Milwaukee became highly contaminated as a result of urban growth and development between the 1900s and 1970s. Rivers like the Kinnickinnic received pollution from various point source discharges, urban runoff, and spills. Such historical practices and lack of regulation resulted in contamination of the sediment with *polychlorinated biphenyls (PCBs)* and *polycyclic aromatic hydrocarbons (PAHs)*. These contaminants accumulated through decades of industrial land use and storm water runoff into the river.

Many regulatory and nonregulatory programs have used pollution point source controls, spill reporting and response, hazardous site cleanups, and *brownfield redevelopment programs* to change polluting industry and urban practices and have significantly reduced the input of contaminants into the Kinnickinnic River and other waters connecting to the Great Lakes. More recently, storm water control requirements are addressing nonpoint pollution sources. Removing contaminated sediments and recreating a useable navigation channel will remove some sources of contamination from the Great Lakes food web and increase the economically important recreational use of these waterways. More recently, storm water control requirements are addressing nonpoint pollution sources. Removing contaminated sediments and recreating a useable navigation channel will remove some sources of contamination from the Great Lakes food web and increase recreational use of these waterways.

Beach Monitoring

In 2003 the Wisconsin DNR, in cooperation and collaboration with local, state, and federal authorities, began implementation of the federal Beaches Environmental Assessment and Coastal Health (BEACH) Act of 2000. The BEACH Act is an amendment to the Clean Water Act requiring all coastal states, including Great Lakes states, to develop programs for

effective water quality monitoring and public notification of water quality conditions at coastal recreational beaches. The EPA has made grants available to participating states to develop and implement a statewide beach program.

The detection of fecal coliform bacteria at levels that require beach closings can indicate the presence of pathogens and other contaminants that could have ecosystem management implications beyond recreation. The Wisconsin DNR maintains website links to a Great Lakes beach health page (<http://www.wibeaches.us>).

Cladophora

Beginning in 2001, large quantities of decaying algae were appearing on Wisconsin's Lake Michigan shoreline. As the algae and organisms trapped in the algae rot, they generate a pungent septic odor that many people confuse with sewage. Nutrient sources (phosphorus), zebra and quagga mussels, declining lake levels, and changing lake currents have been implicated in the recent increase in nuisance algae. The presence of rotting green algae (*Cladophora* spp.) on Lake Michigan beaches presents aesthetic and odor problems that impairs recreational use of Lake Michigan shorelines. These algae do not present a risk to human health (unlike blue-green algae (Cyanobacteria), which can produce toxins). However, the rotting algae provide adequate conditions for bacterial growth. Crustaceans deposited on the beach with the decaying *Cladophora* attract large flocks of gulls, resulting in increased bacteria concentrations from gull fecal material (Wisconsin DNR 2009c).

Cladophora is a green algae found naturally along the Great Lakes coastlines. It grows on submerged rocks, logs, or other hard surfaces. Because quagga and zebra mussels are such efficient filter feeders, Lake Michigan's water clarity

has increased, and *Cladophora* can now grow in well over 30 feet of water depth. Wind and wave action cause the algae to break free from the lake bottom and wash up on shore. Nuisance levels of *Cladophora* were also a problem in the 1960s and 1970s. Research linked these blooms to high phosphorus levels in the water, mainly as a result of lawn fertilizer, poorly maintained septic systems, inadequate sewage treatment, agricultural runoff, and detergents containing phosphorus. Due to tighter restrictions, phosphorus levels declined during the 1970s, and *Cladophora* blooms were largely absent in the 1980s and 1990s. Phosphorus levels in Lake Michigan continue to remain below the thresholds set in the 1970s by the International Joint Commission, but recent research suggests that the invasions of zebra and quagga mussels into the Great Lakes are responsible for the recent increase in *Cladophora* algae. This is due to the ability of the mussels to increase water clarity, which enhances growth of *Cladophora*, and to increase the availability of phosphorus in the nearshore zone, which also benefits *Cladophora*. Zebra and quagga mussels feed by filtering zooplankton, phytoplankton, bacteria, organic debris, and particulate matter such as silt and clay from the water column. This ties up phosphorus, which would normally be consumed by other small organisms, and when the invasive mussels eliminate phosphorus in their feces and *pseudofeces*, it is readily available to *Cladophora* (Pillsbury et al. 2002, Stankovich 2004). For a more detailed explanation of how this works, see the University of Wisconsin Sea Grant website, www.seagrant.wisc.edu.

In 2004 the Wisconsin DNR began an algae, zebra mussel, and nearshore nutrient monitoring program in Lake Michigan to understand the distribution and extent of the *Cladophora* problem. The Wisconsin DNR is currently working in collaboration with the University of Wisconsin-Milwaukee *Cladophora* research program to assist in data collection for a Lake Michigan *Cladophora* growth model that will assist with management efforts. In addition, the Wisconsin DNR is developing guidance and a general permit for *Cladophora* removal and beach management activities. Because we cannot control zebra and quagga mussel populations, the only long-term management option is to reduce phosphorus entering Lake Michigan. Reducing storm water runoff and agricultural runoff and maintaining functioning septic systems are all important to reducing phosphorus loads to Lake Michigan.

Ballast Water Permits

The Wisconsin DNR issues general permits to implement chapter 283, Wisconsin Statutes, regarding control of ballast water discharges. Any ship discharging ballast water in Wisconsin waters of Lake Michigan, Lake Superior, or other state waters must meet effluent standards, monitoring requirements, and other conditions specified in the permit (Wisconsin DNR 2010b). This permit program is intended to help slow the introduction and spread of aquatic invasive species into Wisconsin waters.



Lakeshore development, a common sight in many places in Wisconsin. Northern Highland-American Legion State Forest, Vilas County. Photo by Wisconsin DNR staff.

Asian Carp

The Great Lakes food web has been significantly degraded in recent decades by aquatic invasive species. The migration of Asian carp (i.e., grass carp [*Ctenopharyngodon idella*], silver carp [*Hypophthalmichthys molitrix*], bighead carp [*H. nobilis*], and black carp [*Mylopharyngodon piceus*]) through the Illinois River, Des Plaines River, and Chicago Area Waterway System is the most serious and immediate new aquatic invasive species threat facing the Wisconsin waters of the Great Lakes today. Plankton is the favored food of Asian carp, and they would likely strip the food web of this fundamental resource needed by most young and many adult native fishes.

Federal, state, and local agencies, working together as the Asian Carp Regional Coordinating Committee, are responding to this threat to prevent Asian carp from establishing populations in the Great Lakes (ACRCC 2010). The main objectives of the Coordinating Committee are to

- inform Committee members and others of the urgent actions agencies are taking;
- integrate and unify future actions of responding agencies;
- transition from a single point of defense at the electric barriers to a multi-tiered approach;
- provide general direction while recognizing that agencies require flexibility to best respond;
- recognize potential hurdles that might complicate framework implementation; and
- suggest an approach for stakeholders and other agencies to actively collaborate in future efforts.

Inland Lakes, Rivers, and Streams

Riparian Development

Generally, land cover data and land use analyses show development occurring throughout the entire state. Pockets of extraordinarily rapid development are occurring in the Milwaukee to Madison corridor, the Fox Valley/Green Bay area, and the Hudson/Eau Claire/Chippewa Falls region (proximate to the Twin Cities). A more generalized growth pattern stretches across the entire northern portion of the state. Within each of these areas and beyond, land values for shorelands have escalated, making remaining parcels of undeveloped shorelands even more critical (as they become more rare) for their ecological functions.

Past development practices as well as current trends and practices toward more “manicured” waterfront lawns and more densely developed lakesheds have harmed habitat and water quality on many waters. The amount of polluted runoff entering lakes more than tripled between the 1940s and the 1990s due to increases in the amount of impervious surfaces draining into lakes (Kramasz and Breese 2010). The additional rainwater and nearshore development caused a fivefold increase in sediment entering the lakes. Along with

sediment during and after construction, the phosphorus load entering lakes during this period was 10 times greater in 1990 than in 1940 (Kramasz and Breese 2010). Waterfront property owners, lake associations, and others have taken active roles in improving shoreland management. For the past 10 years and more, the Wisconsin DNR has continued to provide assistance for protecting shorelands and has developed new tools for public education, including guides and videos on how to restore shoreland areas.

Several initiatives at the federal, state, and local levels are ongoing to address the issues of land use and shoreline development:

- The Northern Initiative is a Wisconsin DNR geographically based framework for preserving the fundamental values of wild places in the north.
- Land Legacy is a Wisconsin DNR plan for public land acquisition and easement for the next 50 years.
- Conservation Reserve and Enhancement Program (CREP) is a federal match program to create buffers along waterbodies.
- Smart Growth is a series of state-level requirements for comprehensive planning at the local level that includes identifying key natural resource features in a community.
- The Shoreland Management Program (State/Local) is established in chapter NR 115 of the Wisconsin Administrative Code to protect water quality, wildlife habitat, and natural shoreline beauty through statewide minimum standards for land uses and development adjacent to lakes, rivers, and streams in unincorporated areas.
- Lakes Planning, Protection and Classification Grants (State/Local) provide funds for resource planning and protection at the local level, resulting in initiatives designed to meet the resource protection needs of lakes, based on waterbody characteristics and development potential.
- Rivers Planning and Protection Grants provide funds to protect rivers through resource planning at the local level to help prevent deteriorating water quality, fisheries habitat, and natural scenic beauty as residential, recreational, industrial and other uses increase along rivers.

Size Standards for Piers

A 2008 law set size standards for piers and created a registration process that allows most existing piers larger than the size standards to remain in place. Size standards for pier construction were created because large piers can shade out aquatic plants important to fish and other aquatic organisms and interfere with boaters, swimmers, and others enjoying Wisconsin lakes and rivers. Owners of piers larger than the standards had until April 1, 2011, to complete the pier registration process. A factsheet, video, and interactive decision tool enable pier owners to quickly learn if their pier meets the size standards and is exempt from the registration process.

If the pier is larger than the size standards, the owners can complete a free, one-time registration process. The majority of existing piers already meet these size requirements. However, a March 2012 Wisconsin law (SB 326) establishes an exemption from regulation of all piers existing as of the date of passage. It allows pier loading areas for all existing and new piers of up to 200 square feet. It also allows piers to remain or be placed in areas of sensitive aquatic vegetation, except within Areas of Special Natural Resource Interest identified by statute (meaning pier placement is prohibited only in most State Natural Areas, trout streams, wild rice beds, endangered species habitat, and coastal wetlands).

Dam Safety and Dam Removal

Dam failure can have catastrophic impacts to human safety and property loss as well as to stream habitat and morphology. Wisconsin has a dam monitoring and inspection program to make sure dams are maintained in a safe operating condition. This is especially important as many dams are becoming older.

Dams have significant ecological impacts on streams by restricting the flow of water and movement of aquatic organisms, creating lake-like conditions, and trapping silt behind the dam. More than 100 dams have been removed from Wisconsin streams from the 1960s through 2010, generally with assistance from state dam safety and dam removal grants. Section 31.385 of the Wisconsin Statutes has established two grant programs: the Dam Maintenance, Repair, Modification, Abandonment and Removal Grant program and the Small and Abandoned Dam Removal Grant program. The most significant ecological benefits of dam removal include

- reconnection of important seasonal fish habitat;
- normalized temperature regimes;
- improved water clarity (in most cases);
- improved dissolved oxygen concentrations;
- normalized sediment and energy transport; and
- improved biological diversity (resulting from reestablishing habitat much more favorable for native species such as trout and bass, which can recolonize unoccupied reaches of the river).

Removal of dams will remain an important ecosystem management issue for the foreseeable future. The Wisconsin DNR is working to maintain the dam safety program and dam removal grants as an important part of the Watershed Management program.

Water Quality Monitoring

Because accurate and timely water quality data are important in making watershed management decisions, the Wisconsin DNR Bureau of Watershed Management coordinates a citizen volunteer water quality monitoring program to

assist with assessing the trophic status of the state's waters. These volunteers record regular Secchi depth readings for lakes. While techniques are under development for using satellite data to estimate *trophic levels* and track trends, Secchi readings from these volunteers will be important for calibration of the model used to convert satellite data to a trophic state assessment.

Phosphorus Rules

Wisconsin has 172 lakes and streams on the federal 303(d) impaired waters list for excessive phosphorus. The Wisconsin Natural Resources Board adopted revisions to chapters NR 102 and NR 217 of the Wisconsin Administrative Code in 2010. Included in these rule revisions are numeric water quality criteria for phosphorus in rivers, streams, and lakes, designed to keep waters clear of algae and safe for recreational activities. The other major part of the rule revision of NR 102 and NR 217 prescribes procedures for incorporating water quality-based phosphorus limits in effluent under the Wisconsin Pollutant Discharge Elimination System.

Wisconsin has become the first state in the nation to adopt an adaptive resource management approach that promotes cooperation among point (end-of-pipe or stack) and nonpoint (runoff) pollution sources to find the most cost-effective means to reduce the introduction of phosphorus and other pollutants into the state's waters.

These rules build on Wisconsin law that requires the state to partner with the agriculture community and provide cost-sharing dollars for water quality practices. The Wisconsin DNR works with county land conservation experts and farmers to help producers use best management practices to reduce pollution while helping to implement the most cost-effective solutions. Under this provision, the DNR will provide up to 70% of the farmers' costs of implementing nonpoint source pollution controls to meet the standards of the water quality rules.

Nonpoint Runoff Management

Nonpoint runoff from barnyards and other nonurban, non-industrial and noncommercial land uses can contribute significant amounts of nutrients and harmful pollutants to Wisconsin waterways. To help address this problem, Wisconsin has created a nonpoint targeted runoff management (TRM) grant program. Governmental units and tribes can be reimbursed up to 70% of eligible costs associated with installing best management practices to limit or end non-point source (runoff) water pollution. Grant awards cannot exceed \$150,000. Grants are made for specific projects and have a two-year implementation time frame. TRM grants may not be used to fund projects to control pollution regulated under Wisconsin law as a point source. Examples of eligible projects include

- barnyard and feedlot protection practices,
- design as part of construction,

- detention ponds,
- livestock waste management practices,
- stream bank protection projects, and
- **wetland construction** and restoration.

Efforts are focused in critical watersheds and lakes where nonpoint source-related water quality problems are most severe and control is most feasible. Projects are selected based on a competitive process until all available funds have been allocated.

Agricultural Nutrient Management

Many watersheds and waterbodies in Wisconsin have been negatively impacted by improper farm nutrient management. Large farms and concentrated animal feeding operations can contribute a large share of phosphorus and nitrogen to this problem. Every farm is responsible for properly managing its manure and other nutrients it applies to the land to prevent polluting lakes, rivers, wetlands, and groundwater. There are statewide performance standards and prohibitions that all farms, regardless of size, are obligated to meet to prevent manure running off their land.

In addition, state and federal laws require larger farms, those with 1,000 or more **animal units**, to get water quality protection permits. These permits are issued to ensure that these farms use proper planning, construction, and nutrient management to protect Wisconsin waters. Smaller farms may be required to get permits as well if they've had past manure problems or have other risk factors. The permit requirements, found in chapter NR 243 of the Wisconsin Administrative Code, apply only to water protection. They do not give the Wisconsin DNR authority to address air, odor, traffic, lighting, land use, or other concerns, including the many social concerns people have about large farms.

Storm Water

Storm water from construction sites, industrial sites, agricultural lands, and urban areas has long been a known contributor to water quality problems in Wisconsin. Storm water contributes excessive nutrients, harmful chemicals, turbidity, and excessive temperature increases in many of the state's waterbodies.

Urban storm water runoff and discharges from storm sewers are a primary cause of impaired water quality. Nationally, these sources contribute to roughly 13% of impaired rivers and streams and 18% of impaired lakes (EPA 2000). Storm water runoff from construction activities can have a significant impact on water quality. In addition to sediment, as storm water flows over a construction site, it can pick up other pollutants like debris, pesticides, petroleum products, chemicals, solvents, asphalts, and acids, which contribute to water quality problems.

To meet the requirements of the federal Clean Water

Act, the Wisconsin DNR developed the Wisconsin Pollutant Discharge Elimination System (WPDES) Storm Water Discharge Permit Program, which is regulated under the authority of chapter NR 216, Wisconsin Administrative Code. As part of the EPA National Pollutant Discharge Elimination System, the WPDES Storm Water Program regulates discharge of storm water in Wisconsin from construction sites, industrial facilities, and some municipalities. The goal of the Storm Water Discharge Permit Program is to prevent the movement of pollutants to Wisconsin's water resources from runoff. To achieve this goal, there are two types of storm water permits: construction permits and industrial permits. Construction permits focus on activities that disturb the land during building or construction activities. Industrial permits focus on the activities that occur as part of ongoing businesses operation (e.g., outside storage, utilization of heavy equipment).

Aquatic Organism Passage

Improperly placed or inadequately sized culverts and bridges as well as dams can pose serious barriers to aquatic organism passage, creating fragmented habitat and lowered population diversity and productivity. Fish and invertebrates have different habitat requirements at different seasons and under varying flow conditions, so free access to these various pools, riffles, wetlands, and other habitat features is critical.

The Wisconsin DNR has approached this long-standing issue by establishing the Aquatic Organism Passage Team. Wisconsin DNR staff has helped incorporate fish passage options during Federal Energy Regulatory Commission relicensing of dams. The Fisheries Management program is working with dam owners to design and install **fishways** and **fish lifts** at certain dams. The Office of Energy and Environmental Analysis is working with local governments and road design consultants to ensure that new and replacement culverts and other structures allow free passage of aquatic organisms. Regional Energy and Environmental Analysis staff host training seminars for county road personnel and their consultants.

The U.S. Forest Service's management of the Chequamegon-Nicolet National Forest is an example of how an agency can solve this problem successfully. From 1998 to 2008, the Forest Service replaced 142 of more than 700 of their stream crossings with larger culverts or bridges to minimize erosion and sedimentation, improve channel morphology, restore or improve aquatic organism passage, prevent future failures, reduce road maintenance, and provide a safe, efficient transportation system. The Forest Service continues to improve and refine culvert replacement methods to improve aquatic ecosystem health in the Chequamegon-Nicolet National Forest. Examples of this continuous improvement process include incorporating stream simulation modeling for steep stream segments and considering "**bankfull width**" along with hydrology and hydraulic analysis when designing new stream crossings.

Aquatic Invasive Species

Wisconsin is working to slow the spread of aquatic invasive species in lakes and rivers. Once invasive species become established, it is almost impossible to eradicate them. Therefore, Wisconsin's goal is to keep established invaders like zebra mussels, Eurasian water-milfoil, and quagga mussels from spreading and to keep new invaders like Asian carp from crossing our borders. Wisconsin has responded to invasive species threats by classifying invasive and potentially invasive species through Administrative Rule NR 40 (Wis. Adm. Code). This rule will help control and prevent introduction of the most harmful invasive species. Prevention efforts are increasingly focusing on "source waters" such as the Great Lakes and the Mississippi River.

As of 2009, 75% of Wisconsin lakes with public access were free of Eurasian water-milfoil and zebra mussels; 120 inland waters had zebra mussels; and 479 waters had Eurasian water-milfoil. As of 2012, no new waters were found with Viral Hemorrhagic Septicemia virus since its discovery in 2006. This destructive fish disease has so far been successfully contained in Lake Winnebago and the Great Lakes.

Wisconsin DNR staff and citizens throughout Wisconsin help with this effort by monitoring lakes and rivers for the most problematic aquatic invasive species. The Wisconsin DNR uses these data to make management decisions and to educate boaters and anglers to the presence of invasive species so they do not spread them. The Water Guards program has been effective in helping to slow the spread of aquatic invasive species among Wisconsin's inland lakes. Stationed at high use lakes where the potential for transporting ecologically damaging nonnative species is greatest, Water Guards provide valuable public information and watercraft inspections for the people using those lakes. See the "Invasive Species" section of this chapter for more information.



Hundreds of zebra mussels attached to a single native mussel. Once these mussels are established in a water body, little can be done to control them. Photo by U.S. Fish and Wildlife Service.

Mississippi River

The Mississippi River is the largest river in the upper Midwest, forming most of Wisconsin's western border. It has been negatively impacted by point source and nonpoint source pollution discharges, habitat modification, and barriers to the movements of aquatic organisms posed by the systems of locks and dams.

Long-Term Resource Monitoring Program

In order to address these impacts, the Long Term Resource Monitoring Program was authorized by Congress in 1986 as part of the U.S. Army Corps of Engineers' Environmental Management Program on the Upper Mississippi River (UMR). This program is being implemented by the U.S. Geological Service with assistance and field support by the five UMR states (Minnesota, Iowa, Wisconsin, Illinois, and Missouri). It has been in place since 1988 and provides information on water quality, vegetation, fisheries, and land cover/land use and other resource information used to assess the trends and ecological health of the river. The Wisconsin DNR's field station at La Crosse conducts the Wisconsin part of this monitoring program.

In 2009 an updated Strategic and Operational Plan for the Long Term Resource Monitoring Program was approved by the partnership for 2010–2014. The plan defines a process for prioritizing research and reinstates some fisheries and water quality monitoring that was cut in the previous plan.

The Upper Mississippi River Basin Association

The Upper Mississippi River Basin Association (UMRBA) is a regional interstate organization formed by the governors of Illinois, Iowa, Minnesota, Missouri, and Wisconsin to coordinate the states' river-related programs and policies and work with federal agencies that have river responsibilities. UMRBA is involved with programs related to ecosystem restoration, hazardous spills, and water quality as well as floodplain management and flood control, commercial navigation, and water supply.

Gulf of Mexico Hypoxia

Two-thirds of the land area of Wisconsin is in the Mississippi River drainage basin. The river corridor itself is a major ecological resource and interstate transportation asset. Human activities and land uses in the watershed have increased sediment and nutrient problems in the river. Sediment can fill in backwater areas, increase turbidity, and deposit pesticides and other toxic chemicals. Thirty-one percent of the nutrients reaching the Gulf of Mexico come from the Upper Mississippi River Basin, contributing to *Gulf Hypoxia* and the highly degraded area known as the "Dead Zone." Wisconsin DNR's Mississippi River basin-wide activities include working with the Gulf of Mexico Hypoxia Task Force, which includes implementation and documentation of nutrient reduction activities in the State of Wisconsin.

Fisheries

The status of Wisconsin's diverse fish biota is a reflection of the health of the waters they inhabit. Management of sport fishing, an important component of the state's economy, can affect nongame fish, so managers are trying to protect habitat values for all native species. In the northern third of Wisconsin, sport fish management is also influenced by the need to incorporate tribal treaty harvest rights, while industrial and other impacts must be considered in light of tribal water quality standards.

Viral Hemorrhagic Septicemia

Viral Hemorrhagic Septicemia (VHS) is a disease that can infect several dozen fish species in Wisconsin, causing them to bleed to death. A recent Michigan State University study shows that muskellunge (*Esox masquinongy*) are most susceptible to VHS, followed by largemouth bass (*Micropterus salmoides*), yellow perch (*Perca flavescens*), rainbow trout, brook trout (*Salvelinus fontinalis*), brown trout, Chinook salmon, and Coho salmon (*Oncorhynchus kisutch*). The virus was first detected in Wisconsin in May 2007 when dead fish collected from the Lake Winnebago and Lake Michigan systems were tested and were positive for the virus. Lake Michigan fish again tested positive for the virus in 2008 and 2009. No spread has been found outside of Lake Michigan or the Green Bay-Fox River basin.

The Wisconsin DNR initiated an extensive public education program, and the Natural Resources Board passed rules restricting bait harvest and transportation of live fish from these infected waters. Wisconsin DNR research staff embarked on a program to learn more about this disease. Two projects will examine the effects of temperature on VHS and the effects of the disease on fish populations, develop improved testing procedures, and provide information related to the ecology of the disease itself. In addition, fish have been tested for VHS in waterbodies where it has not been found to date.

The Fish Management program reported that this potentially deadly fish virus did not spread to any additional inland Wisconsin waters that were tested for the virus in 2010. None of the fish that Wisconsin DNR fisheries biologists collected from nearly 70 lakes and rivers in the spring of 2011 tested positive for VHS. Monitoring and testing will be ongoing for the foreseeable future.

Spring Pond Project

The mixed gravel and sandy bottoms of some spring ponds in northern Wisconsin have become covered with silt and debris, which is believed to reduce the habitat values of these waters for native brook trout. A program to remove this silty material has demonstrated that this activity can help improve trout habitat, but it is unclear what impacts it has on other coldwater fauna. A number of such ponds, especially in the northeast portion of the state, have had silt dredged

from them to set back this natural process in order to provide habitat for native brook trout populations.

"Get the Lead Out" Campaign

Lead fishing tackle has been found in the stomachs of Common Loons (*Gavia immer*) and other wildlife in Wisconsin, and some Common Loons have been found to have elevated blood levels of lead. High lead levels can negatively impact the reproductive success, and very high levels can be lethal to adult Common Loons. Wisconsin DNR has embarked upon a "Get the Lead Out" public education campaign to encourage anglers to switch to non-lead versions of jigs, sinkers, and other tackle to remove this wildlife health hazard. Non-lead tackle is still not common in Wisconsin sporting goods stores, so this project will continue.

Habitat Restoration Work

Decades of poor land use practices such as overgrazing, streambank grazing, development that generates excessive storm water, wetland drainage, past deforestation, mining, and other activities have severely degraded some lake and stream habitat in the state. Wisconsin DNR has been working for decades to repair this damage.

Wetland Protection and Restoration

A key element of wetland protection in Wisconsin continues to be public education. Wisconsin DNR has engaged in a number of projects aimed at increasing public awareness of and compliance with certain rules established to protect aquatic biological diversity in shoreland and wetland areas. In October 2008, Wisconsin DNR released a new online informational tool kit to help thousands of Wisconsin property owners learn whether they have wetlands on property they want to buy or build on, when wetlands are not readily apparent (Wisconsin DNR 2012d). Components of this tool kit include a Wetland Indicator Map, a physical clues checklist, a real estate addendum to be used with a real estate Offer to Purchase, and a link to an informational video, *Waking up to Wetlands*.

The Wisconsin DNR Wetlands program developed the electronic Wetland Indicator Map layer with a user guide (see <http://dnr.wi.gov/topic/wetlands/mapping.html>). This can be used in conjunction with the Wisconsin Wetland Inventory layer to make a preliminary determination of the potential for wetlands on a given property. Color coding on the map will show whether the property has soils commonly found in wetlands. Other shading indicates areas confirmed as wetlands that are mapped on the Wisconsin Wetland Inventory. If the map shows the confirmed or potential presence of wetlands, a wetland professional should be contacted for an on-site investigation of the property. Only a wetland professional listed in a directory jointly maintained by WDNR and the U.S. Army Corps of Engineers can verify whether wetlands are present on a property and delineate their location (Wisconsin DNR 2012a).

Shoreland Wetland Zoning

Counties, cities, and villages are required to adopt shoreland wetland zoning ordinances to regulate activities in shoreland wetlands. Shoreland wetlands are those wetlands that are 5 acres in size or larger and are located in the shoreland zone. Communities may decide to zone wetlands that are smaller than 5 acres or outside the shoreland zone. The shoreland zone is land located within 1,000 feet of the ordinary high water mark of a lake, pond, or flowage; within 300 feet of the ordinary high water mark of a river or stream; or to the landward side of the floodplain, whichever distance is greater. This shoreland zone provides critical habitat for many of the aquatic plants and animals essential to keeping our waters clean, healthy, and productive.

Ephemeral Ponds

Ephemeral Ponds are unique ecosystems that not only can serve as sites for groundwater infiltration and recharge but also provide food and critical habitat for both terrestrial and aquatic organisms. Encysted fairy shrimp (Family *Chirocephalidae*) eggs have been found under layers of sediment, indicating that these eggs can remain viable for many years until hatching conditions again return. Ephemeral ponds are often small, can be difficult to identify, and are vulnerable due to their generally small size, some use traditions (which have included filling and dumping), and isolation by various developments. Wisconsin has been investigating means to rapidly identify potential ephemeral ponds using topographic mapping data and is also establishing an Ephemeral Pond Citizen Monitoring Network in southeast Wisconsin. On public forestlands, some ephemeral ponds will be protected by following the best management practices described in *Wisconsin's Forestry Best Management Practices for Water Quality: Field Manual for Loggers, Landowners, and Land Managers* (Wisconsin DNR 2010d).

Reversing the Loss

The Wisconsin DNR Wetlands Team has developed a strategy to reverse wetland losses, published as *Reversing the Loss: A Strategy to Protect, Restore and Explore Wisconsin Wetlands* (Wisconsin DNR 2008). Wisconsin DNR Wetlands Team members develop a biennial Reversing the Loss Action Plan, detailing activities for implementing the Reversing the Loss strategy over each two-year period. The current (2010) implemental plan has many items that will help reverse Wisconsin's wetland loss, including

- establishing a "Wetland Protection and Restoration Grant Program" to maintain desirable wetland functions and values or to restore altered wetlands and buffer areas;
- supporting the development of local incentives for protecting and restoring wetlands through county and local comprehensive planning efforts;
- creating awareness of wetland laws through expanding the Wetland tool kit and other means;

- promoting and demonstrating wetland values;
- promoting citizen wetland monitoring networks and results;
- reducing illegal wetland filling activities and increasing water quality certification permit compliance;
- developing and implementing wetland protection tools for use in local planning and development processes for purposes of increasing public awareness and improving wetland protection and stewardship initiatives;
- minimizing impacts and preventing storm water discharges to wetlands, whenever possible; and
- restoring wetlands in an efficient manner to maximize limited funding, address identified needs, and benefit both the natural resource and Wisconsin residents. Where appropriate, restoring and acquiring rare and declining wetland types and wetland complexes, considering wetland types that were present historically in each ecological landscape.

Wetland Restoration

Because wetlands generally have both a habitat and a hydrological function, the carefully planned restoration of areas of degraded wetland will be an important activity for decades to come. Wisconsin DNR has a wide assortment of web-based video and written information aimed at helping interested individuals and groups develop and implement successful wetland restoration projects.

An important aid in restoring wetlands is a set of maps showing where wetland soils have been documented. The Wetland Indicators Map by the U.S. Department of Agriculture Natural Resources Conservation Service shows soils mapped in the drainage classes of "somewhat poorly," "poorly," and "very poorly drained" soils. Areas with soil types within these drainage classes are typically designated as wetlands. Therefore, this map layer can be used to identify potential wetlands. For more information on mapped soil types, see the USDA Natural Resources Conservation Service Web Soil Survey website (<http://websoilsurvey.nrcs.usda.gov/app/>).

Groundwater Depletion

There continues to be growing demand for clean groundwater in Wisconsin, with dwindling supplies in some areas. In the last half-century, Wisconsin has gained more than two million new residents, and groundwater use has greatly increased. Today, Wisconsinites use one-third more water (189 million gallons more per day) than 15 years ago. The number of irrigated farm acres in Wisconsin has tripled since 1969, from 105,526 to over 390,000 acres. Irrigation equipment withdraws 182 million gallons per day in the growing season, almost all of it from groundwater.

Increased water use is depleting aquifers in some parts of Wisconsin, with consequences for public health, populations of plants and animals with groundwater-dependent

habitat needs, and the streams, wetlands, and other waters that depend on groundwater. Large-scale withdrawals of groundwater are adversely affecting the environment, economy, and public health in large areas of Wisconsin. These drawdowns of aquifers can cause the water level in wells, lakes, streams, and wetlands to drop or cause them to dry up entirely. Drawdowns can also cause the levels of arsenic, radium (the precursor to radon), and salinity in drinking water to increase. For instance:

- In Dane County, water levels in the deep aquifer from which Madison and its suburbs draw water have dropped more than 60 feet from levels before extensive urbanization.
- Groundwater levels in aquifers in some areas of southeastern Wisconsin have dropped more than 450 feet below original levels due to intensive pumping. Such drawdowns can harm groundwater quality and also require that new wells are drilled deeper, making them more expensive. The flow of groundwater into lakes, streams, and wetlands—particularly calcareous fens, which are more common here than elsewhere in the state—can be reduced, hurting fish, wildlife, and plant populations.
- Arsenic contamination in parts of Winnebago and Outagamie counties are being exacerbated by the increasing demand for water. Experts believe the 1,000 new wells drilled in that area every year are introducing oxygen into the aquifers and triggering geochemical reactions that release arsenic from the bedrock (Riewe undated).

Sources of high salinity and radium are being investigated in the deep sandstone aquifer that supplies water to residents of eastern Wisconsin (Grundl and Bradbury 2006). This project is examining the chemistry of the groundwater and the rock formations of this complex aquifer to determine whether high pumping rates are raising salinity and radium levels. This information will help city planners and water utility directors better understand the relationship between well operations and water quality in this region and evaluate effects of urban growth on water supplies.

In late 2007, suburban communities in the Lower Fox Valley reduced consumption of groundwater by switching to surface water supplied by a pipeline from Lake Michigan. As a result, water levels in the deep sandstone aquifer near Green Bay have begun to recover. The water levels had risen by 100 feet in much of the region and, in some wells, by more than 150 feet. The rate of recovery has now significantly slowed, suggesting that nearly all of the recovery in this aquifer has occurred.

Other research has investigated the viability of aquifer storage and recovery (ASR) for Wisconsin, where excess water is stored in aquifers when demand is low and withdrawn for use when demand increases (Lowry and Anderson 2003). Computer models of groundwater flow and transport in ASR systems have been developed for two representative groundwater systems in Wisconsin. A better understanding

of pumping rates, storage times, and other factors that affect recovery efficiency of ASR systems has helped guide decision making about using these systems in Wisconsin.

Groundwater Degradation

Runoff from the use of agricultural chemicals and fertilizers, industrial spills, and other sources can affect waters. As land uses and resource demands intensify with increasing populations and as new potential contaminants are created by emerging technologies, groundwater monitoring will be needed. Testing public and private water supply wells can potentially alert watershed managers to groundwater contamination and may indicate threats to surface waters that receive groundwater recharge.

Endocrine-Disrupting Chemicals in Karst Formations

A study titled “Assessing Levels of Endocrine Disrupting Chemicals in Groundwater Associated with Karst Areas in Northeast Wisconsin” was completed in 2011 (Bauer-Dantoin et al. 2011). This research project assessed groundwater movement and contaminant transport through carbonate bedrock areas in four counties in northeastern Wisconsin. The carbonate bedrock areas chosen for study have shallow soil depths and karst features and are considered to be very vulnerable to contamination leaching from the ground surface. The research specifically evaluated the fate and transport of *endocrine-disrupting chemicals (EDCs)* in groundwater associated with the land application of dairy waste on soils above the vulnerable bedrock aquifer.

Pharmaceuticals, Personal Care Products, and Endocrine-Disrupting Compounds

The Wisconsin DNR is using the results of pharmaceutical, personal care products (PCPs), and EDC research studies to evaluate whether current state groundwater protection regulations are adequate to address potential adverse impacts from the discharge of these substances. Improper disposal of pharmaceuticals can result in heavy metals, endocrine-disrupting chemicals, and antimicrobial materials in surface and ground water where they can affect aquatic life and human health. Studies comparing the levels of pharmaceuticals, PCPs, and EDCs present in wastewater influent with treatment system effluent provide information on the removal effectiveness of wastewater treatment processes. Research into the behavior of pharmaceutical, PCP, and EDC substances in soil and groundwater is helping the Wisconsin DNR develop effective monitoring strategies. Studies evaluating new sampling techniques and analytical test methods have helped ensure that the Wisconsin DNR is utilizing the best available tools to assess the occurrence of these substances in the environment.

Arsenic in Northeastern Wisconsin

Two studies in the Wisconsin DNR Northeastern Region (Stoll 1992, 1994) identified arsenic contamination in groundwater. Homeowners were alerted through direct mailings,

public meetings, and mass media news releases. Continuing educational efforts and studies were done to alert 72,000 people of their potential exposure to the substance in their drinking water. In one of the studies, which the Wisconsin DNR coordinated with the Wisconsin Department of Health and Social Services, more than 2,200 households submitted samples and returned health surveys, providing health and exposure information for 6,669 individuals. Approximately 20% of the water supplies contained arsenic levels above 10 µg/L. Slightly more than 10% of the families consumed water that had an arsenic level greater than 20 µg/L. People over the age of 50 were more likely to report a diagnosis of skin cancer if they had consumed water that had an arsenic concentration greater than 5 µg/L for 10 years or more. No association was seen between exposure to arsenic-contaminated water and the incidence of other types of cancer. However, findings from this study were consistent with previously reported associations between arsenic exposure and the prevalence of adult onset diabetes and cardiovascular disease.

An “Arsenic Advisory Area” was established in the early 1990s in east central Wisconsin that encompassed land for 5 miles on either side of the buried St. Peter Sandstone bedrock, extending in a northeasterly trend, roughly between Oshkosh and Green Bay (WGCC 2012). For this area, the Wisconsin DNR developed special well construction specifications that were more stringent than the minimum Private Well Code requirements. In 2002 the Wisconsin Geological and Natural History Survey completed field studies that demonstrated that high levels of arsenic in groundwater minerals are oxidized in well boreholes. Two distinct geochemical mechanisms appear to contribute to unhealthy arsenic concentrations in well water in this aquifer: (1) oxidation of sulfide minerals due to a combination of groundwater level drawdown, standard well casings that conduct air to the groundwater supply, and natural processes and (2) reductive dissolution of arsenic-bearing iron oxides. Ongoing efforts to address this problem include compilation of private well sampling results. The goal is to continue identifying areas in Wisconsin with relatively high numbers of wells adversely affected or potentially adversely affected by naturally occurring arsenic as well as to evaluate the effectiveness of the more stringent well casing requirements.

Atrazine from Agricultural Practices

In the mid-1980s, the corn herbicide atrazine was first detected in monitoring wells and private drinking water wells in Wisconsin. A state-funded well survey estimated that atrazine was present in 12% of Grade A dairy farm wells in the state. The University of Wisconsin Water Resources Center conducted a detailed hydrogeologic study (Chesters et al. 1991) at a farm in Dane County and showed conclusively that atrazine contamination could result from both field applications and mixing/loading practices. With the knowledge that nonpoint source contamination of groundwater by atrazine was indeed occurring, the Wisconsin

Department of Agriculture, Trade, and Consumer Protection (DATCP) developed ways to reduce this contamination (the Atrazine Rule; DATCP 30, Wis. Adm. Code).

Several research projects conducted by the University of Wisconsin-Madison Department of Soil Science (Daniel et al. 1989, McSweeney et al. 1991, Wietersen et al. 1993) found that areas appearing similar in soils and agricultural practices had significantly different susceptibility to contamination. This information had a direct influence on the atrazine rule, requiring different application rules in different parts of the state. For example, there is now a prohibition of atrazine use in the Lower Wisconsin River Valley and a managed use in the sandy soils of central Wisconsin (primarily in the Central Sand Plains Ecological Landscape).

As more research was conducted, three *metabolites* of atrazine that were of serious health concerns were found to be present in groundwater (LeMasters and Doyle 1989, Cates 1990, Chesters et al. 1991, Cowell 1992, LeMasters and Baldock 1997). This knowledge allowed Wisconsin DNR to strengthen the groundwater standard for atrazine in 1992 and allowed DATCP to strengthen the atrazine rule in 1993 and extend required use reductions to the entire state. Since the atrazine rule is based on science and was applied in a “fair” manner that recognizes variable soil and bedrock conditions across the state, the atrazine rule has experienced a relatively high degree of acceptance.

Manure Spreading and Groundwater

The Wisconsin DNR has developed public education messages encouraging landowners to adopt practices that will control land spreading of manure and protect ground and surface water quality. See the “Agricultural Nutrient Management” section above.

Emerging Aquatic Resource Issues

There are several important emerging issues involving aquatic resources. Some are new, such as the effects of climate change and pollutant trading, and others are modifications of strategies used to address past and current problems, such as ways to address use of pesticides.

Climate Change

Information available at the Wisconsin Initiative on Climate Change Impacts website (WICCI 2010b) indicates that over the time period from 1950 to 2006 Wisconsin’s climate has already shifted to a warming trend as well as had changes in precipitation patterns. See the “Climate Change” section at the beginning of this chapter for more details.

The Wisconsin DNR’s Bureau of Watershed Management has developed a climate change strategy with four overall goals:

1. Minimize threats to public health and safety by anticipating and managing for extreme events (floods and droughts)

2. Increase resiliency of aquatic ecosystems to buffer the impacts of future climate changes by restoring or simulating natural processes, ensuring adequate habitat availability, and limiting population level impacts of human activities
3. Stabilize future variations in water quantity and availability by managing water as an integrated resource (by “keeping water local”) and supporting sustainable and efficient water use
4. Maintain, improve, or restore water quality under a changing climate regime by promoting actions to reduce nutrient and sediment loading

Pollutant Trading

Watershed-based pollutant trading allows one party to abstain from additional pollutant discharges while allowing another to discharge more, using a contractual agreement and payment system between the parties involved in the trade. Watershed-based pollutant trading is a tool used in watershed management where all emitting sources contribute to reducing pollution without any one entity bearing an excessive financial burden. This shift in responsibility may result in a more equitable, efficient, cost-effective means to address water quality problems in a watershed.

After four years of implementing pollutant trading pilot projects in Wisconsin, no actual trades have occurred, but they have created a greater understanding of why trading may or may not be successful. The following points summarize what has been learned to date (Wisconsin DNR 2011):

- Most wastewater treatment plants can more economically meet an effluent limit of 1 mg/L phosphorus through plant upgrades than through trading.
- For trading to be effective, a broker, such as the County Land Conservation Department or the Wisconsin DNR, should assume the administrative costs. The broker will need a source of funds to function in this capacity.
- Trading is more likely to be economical if the phosphorus load to be traded is relatively small.
- The effluent limit of 1 mg/L phosphorus is not an adequate driver to support trading in most instances. A Total Maximum Daily Load performance standard or water quality based limit is needed to elicit interest based primarily on cost considerations.
- An agreed-upon set of tools is needed to quantify phosphorus reduction loads from nonpoint sources.

Pesticide Permits

Pesticide residues are sometimes detected in organisms living in many Wisconsin waters, especially in watersheds with substantial agricultural and urban land uses. These substances can *bioaccumulate* up the food chain of aquatic

organisms where they have the potential to exhibit effects on reproduction or survival. Some people in Wisconsin feel it would be beneficial to regulate pesticide use through general pesticide permits for control of

- nuisance aquatic plants and animals (that will integrate with the existing chapter NR 107, Wis. Adm. Code, aquatic plant management permit program);
- invasive aquatic organisms (such as purple loosestrife and zebra and quagga mussels); and
- terrestrial pest management via aerial spraying (such as adult mosquitoes and forest canopy pests).

Wisconsin DNR is planning to incorporate the EPA treatment-based requirements (minimized pesticide use in accordance with preventing development of pesticide resistant organisms, integrated pest management, and a pesticide discharge management plan) into the Wisconsin general permits.

State of Washington pesticide permits will serve as a model. Washington has addressed this issue since 2002 and has had pesticide pollutant discharge permits in place for years. Wisconsin is hoping to implement an internet-based application process for all pesticide discharge general permits, similar to the State of Washington system.

For National Pollutant Discharge Elimination System permits, the State of Washington references a list of approved pesticides that may have a residual discharge to state waters under the general discharge permit, with provisions for approval of additional pesticide active ingredients after extensive state review. The Wisconsin Pollutant Discharge Elimination System permits will be designed to protect state surface and ground waters. A single permittee for each general permit, either the owner or the operator, is desired.

Total Maximum Daily Load

The Wisconsin DNR is responsible for administering the federal Clean Water Act, which has as its primary objective the restoration and maintenance of the chemical, physical, and biological integrity of the nation's waters. A key part of this responsibility is to identify which lakes, rivers, and streams are not meeting applicable water quality standards. That list of waters becomes the core of Wisconsin's Impaired Waters program and is updated and submitted to EPA once every two years as required by Section 303(d) of the Clean Water Act.

Removing waters from the Impaired Waters list most often requires a Total Maximum Daily Load (TMDL) report that evaluates all sources of a pollutant and then allocates the amount that each of those sources can emit in order to achieve water quality goals for the receiving water. Sources of pollutants can be numerous and include but are not limited to runoff from farms or urban streets, effluent discharges from wastewater treatment plants, atmospheric deposition, and contaminated sediments at the bottom of lakes and

streams. In 2010, Wisconsin has about 700 waters on the list. Nearly 50% are due to the atmospheric deposition of mercury, which drives restrictions on how many fish can be consumed to avoid human health problems. Excessive deposition of sediment and phosphorus-laden runoff are the two other primary causes of water quality problems in the state, causing many waters to be on the Impaired Waters list.

The Wisconsin DNR relies solely on federal funding for support to develop and implement TMDL reports. While a goal exists to complete at least 15 TMDL reports annually, resources and select state and federal policies (or lack thereof) are a limiting factor, and reaching that goal is often challenging. In 2012, the Wisconsin DNR is actively developing several large-scale, basin-wide TMDL reports, including studies for the Lower Fox River Basin plus lower Green Bay Basin, the Upper Fox/Wolf River Basin, the Rock River Basin, and the Central Wisconsin River Basin (including Lake Wisconsin). A number of smaller-scale TMDL reports have already been completed or are currently under development.

White-Tailed Deer Impacts on the Ecosystem

White-tailed deer can dramatically impact the composition, structure, and function of ecosystems, especially when they are present in high numbers. High deer numbers have become a management challenge in Wisconsin forests as well as much of eastern North America. Maintaining healthy ecosystems, producing forest products, and, at the same time, maintaining socially acceptable deer population levels will be a major challenge for the foreseeable future. This section provides a brief background on white-tailed deer in Wisconsin and some of the major ecological and social issues associated with them. The Wisconsin DNR completed an environmental assessment of deer impacts on ecosystems in 1995 (VanderZouwen and Warnke 1995), which contains a more detailed discussion of specific effects of deer on different ecological and social resources. This section is heavily based on the information found in the 1995 report. A recent literature review of deer impacts on ecological resources can be found in Waller et al. (2009). Major conclusions in this section are as follows:

- Statewide, deer populations have been at unprecedented highs since the 1980s.
- Deer numbers, although lower than in the 1940s following the Cutover when widespread winter starvation occurred, are higher than prior to Euro-American settlement in northern Wisconsin. Deer populations in southern Wisconsin are dramatically higher than they were prior to Euro-American settlement.
- High deer numbers are having profound ecological and social impacts.

- Deer management is a complex issue with numerous citizen perspectives, demands, and strongly held values.
- A thorough broadscale evaluation of deer management that includes a long-term perspective is needed, which includes the ecosystem factors discussed in this handbook. Deer managers should recognize the need to maintain all components of ecosystems, sustain important forest industries, and limit impacts to human health while maintaining an adequate deer herd for hunting, an economically and culturally important practice with a long history in Wisconsin.

White-tailed deer feed primarily on woody browse in the winter, leafy browse and herbaceous plants during the growing season, and mast (acorns, cherries, berries, and other seeds) and agricultural crops when they are available. Food within 7 feet of the ground is usually considered within reach of deer. Deer are selective in the food they eat, preferring some plant species over others, but they consume a large number of plant species during the summer months.

Deer can become numerous enough to impact their food source. *Density-dependent mechanisms* can slow the rate of population growth, but habitat damage commonly occurs before these mechanisms act. *Density-dependent responses* in the reproductive rate of deer are imperfect, and the mechanisms that slow population growth are not always finely tuned to the environment. Additionally, deer and deer habitat are affected by density-independent factors, such as drought or severe cold and deep snow. This is well recognized in the northern areas of the state where seasonal deer densities change dramatically in relation to the food resources available. In the 1990s, baiting and feeding deer became popular; hunters used corn and other foods as bait, and more northern residents fed deer during the winter, often in their backyards, artificially adding food to the environment during the winter months. This may have raised the *carrying capacity* for deer in northern Wisconsin, allowing for larger deer populations, which can have an even larger impact on native vegetation.

Deer are not evenly distributed across the state in space or time (Figure 5.2), and they concentrate in favorable habitats during winter and summer, especially in northern Wisconsin. Deer have well-developed home ranges (about one square mile) and social systems that maintain a hierarchy for access to food resources. These factors influence the reproductive potential of different age cohorts of female deer. Deer are found in many different ecosystems and habitats, from urban and agricultural areas in the south to managed forests and wilderness areas in the north. Different habitats and ecosystems support varying densities of deer, and populations change over time, especially in the north where the severity of winter weather can influence population size. Statewide, hunting by humans is the main method of controlling deer populations.

Role of White-Tailed Deer in the Ecosystem

White-tailed deer can affect ecosystems in a number of ways. Overabundant deer populations can stress native plants by overbrowsing, reducing, or eliminating those species (Vander-Zouwen and Warnke 1995). (See “Impacts on Herbaceous Plants” and “Impacts on Woody Plants” below.) As plant species composition is changed, other less desirable plants or invasive species can increase. Large numbers of deer are also associated with a reduction in the number, density, and diversity of groundlayer plants, including shrubs, needed by some birds, small mammals, and insects for breeding, nesting, foraging, and escaping predators. Large numbers of deer can also affect tree regeneration and tree species composition of the forest. Deer preferentially browse certain species, and different tree species have varying defenses to browsing (e.g., fast growth rate and different growth forms).

Deer management within a science-based, ecosystem management context aims for a deer herd size that will allow all plants and animals within an ecosystem to survive and maintain their populations indefinitely. Therefore, deer population goals in Wisconsin have historically been set relative to the carrying capacity of the environment for deer. It was previously believed that deer populations below 70%–75% of deer carrying capacity did not result in unacceptable levels of environmental alteration, and population goals in Wisconsin’s forested units were usually set to about 60%–65% of deer carrying capacity (Wisconsin DNR 2001). However, research has suggested that much lower deer populations may be needed to maintain viable populations of browse-sensitive plants (Alverson et al. 1988, deCalesta and Stout 1997).

The historical landscape in Wisconsin was very different from today. Suitable deer habitat is now very abundant in much of the state. Wisconsin’s northern forests were almost entirely logged, and much of that area was also burned. In the south (and in parts of the north), there was widespread conversion of hardwood forests, savannas, and prairies to agricultural lands. Many forests, especially in the south, have been fragmented into small patches surrounded by fields of agricultural crops.

High deer densities in the north in the 1930s–40s may have had impacts on plant species composition that still persist in some forest habitats today, especially in deer winter concen-

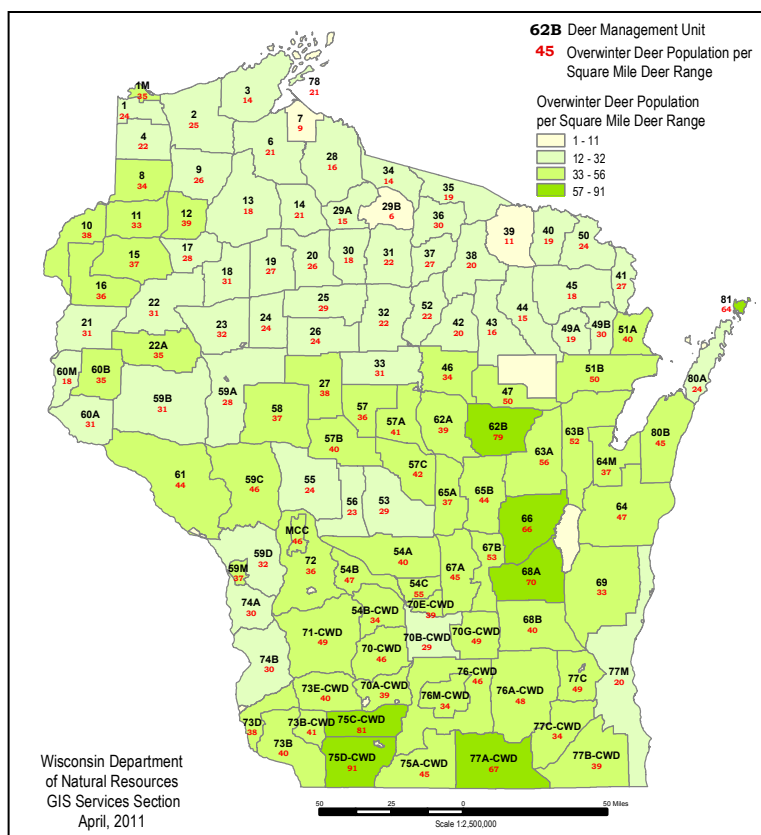


Figure 5.2. Overwinter deer densities per square mile of deer range, 2010.

tration sites, such as northern white-cedar (*Thuja occidentalis*) swamps, and eastern hemlock stands. Also, although populations are lower now, many of these forests continue to experience heavy browse pressure and continued reproductive failure by sensitive tree species.

The sustainable management of terrestrial ecosystems for the benefit of current and future generations is a key issue. In addition to the impacts to plant species composition, overabundant deer are associated with other significant problems, including lack of forest regeneration, agricultural damage, deer-vehicle collisions, damage to ornamental plants in urban settings, and spread of disease. These problems affect most citizens of Wisconsin through impacts on ecosystem services, recreation, and economics. A broadscale and long-term evaluation of deer populations and their impacts on the environment is needed for the best chance to maintain Wisconsin’s ecosystems and their components. There are many studies on the impacts of deer at very low and high densities, but there are few studies of known deer densities within which most deer management occurs (15–30 deer per square mile). A management emphasis that focuses solely on maintaining high numbers of deer across much of the state to benefit a relatively small segment of the human population is likely to have serious ecological and socioeconomic consequences for the rest of the citizenry.

Ecological Impacts

As a *keystone herbivore*, deer impact the habitats in which they live. As deer numbers increase, some plant species preferred as food become less abundant or are lost (Wisconsin DNR 2001). Other native and nonnative

plants may increase in abundance. This can lead to a simplified forest ecosystem and shift the species composition of the forest. These effects can cascade to other species and reduce overall biodiversity. Higher deer densities are often associated with more severe negative habitat impacts, and there is concern that some impacts may be very long-lived and difficult to reverse (Côté et al. 2004, Tremblay 2005). The following discussion describes the impacts that deer can have on herbaceous plants, woody vegetation, birds, mammals, herptiles, and other animals, and the spread of invasive species.

Impacts on Herbaceous Plants

White-tailed deer eat a wide variety of herbaceous plants during the growing season, including species from 70 genera and/or families in northern Wisconsin and 53 in the southern Wisconsin (VanderZouwen and Warnke 1995). Herbs support the majority of the plant diversity in forests and affect overall forest dynamics because even tree seedlings pass through this layer (Waller et al. 2009). Herbs are susceptible to repeated herbivory by deer because they never grow tall enough to be out of reach. Plant species most likely to be negatively impacted by deer herbivory include those that are rare, short lived, produce only single stems, occupy restricted habitats, or are preferred as food by deer. The latter group includes plants that humans appreciate such as orchids, trilliums, and other species in the lily family (Miller et al. 1992). The Wisconsin DNR's environmental assessment of deer impacts on ecosystems lists 154 species of herbaceous plants eaten by deer (VanderZouwen and Warnke 1995). Major families are Asteraceae, Fabaceae, Liliaceae, Orchidaceae, and Rosaceae. Preferred genera in Asteraceae include *Aster*, *Lacutuca*, and *Prenanthes*. In the Liliaceae family, deer prefer plants in the genera *Lilium*, *Smilacina*, and *Trillium*. The list contains six species that are Wisconsin Endangered, eight that are Wisconsin Threatened, and five that are Wisconsin Special Concern. Four species are also federally listed. Three rare plant species thought to be at particular risk are Indian cucumber-root (*Medeola virginiana*), showy lady's-slipper (*Cypripedium reginae*), and prairie white-fringed orchid (*Platanthera leucophaea*).



Exclosure in Vilas County showing dramatic differences in vegetation due to deer herbivory. Photo by Thomas Rooney.

Deer browse can lead to simplification of prairies and other grassland ecosystems because deer preferentially browse the forb species in these communities (Anderson et al. 2001). Forbs are important for numerous butterflies and other taxa, and they sometimes occur in low abundance relative to the dominant **graminoid species**. Some research has suggested that light levels of browse may actually stimulate forb diversity (Anderson et al. 2005), but more information is needed regarding how the level of browse intensity varies with many factors at species, habitat, and landscape levels.

Deer impacts to forest ecosystems have received much attention in recent years. Browse impacts to tree species have received the most study because of implications for forest regeneration; however, research suggests that deer can dramatically impact the entire understory. Deer impacts affect certain herbaceous plants more than others. For example, graminoids and ferns are much less susceptible to deer impacts than forbs (Rooney 2001, Rooney 2009), and recent studies have shown that certain forbs are preferentially selected. Dramatic contrasts are often exhibited between areas where deer have been intentionally excluded and where they have not, although these examples may still underestimate impacts since the **exclosures** are often installed in areas that have been repeatedly impacted by deer before the exclosure was erected. In Pennsylvania and Wisconsin forests, Rooney (2001) found that between 48% and 81% of the understory species disappeared within a few decades in heavily browsed areas. Rooney et al. (2004) found that sites without deer hunting (state parks in this study) lost 60% of their understory species in the past 50 years, compared with a 16% loss at hunted sites in their surveys of the herbaceous vegetation of forested natural communities in northern Wisconsin. Adverse effects on vegetation may persist for more than 30 years, based on a study in the Apostle Islands (Balgooyen and Waller 1995). In some forests, understory layers are dominated by one or very few species tolerant or resistant to herbivory, including invasive species such as garlic mustard or certain natives such as jack-in-the-pulpit (*Arisaema triphyllum*), Virginia creeper, and cherries (*Prunus* spp.) (Rooney et al. 2004).

There could be synergistic effects of herbivory by white-tailed deer and the activities of invasive earthworms on the decline of native plants (Frelich et al. 2006). Holdsworth et al. (2007) found no significant interaction between

the intensity of earthworm invasion and the index of deer browse in the Chequamegon National Forest. Nuzzo et al. (2009) suggested that the decline of many native plant species may be caused by a combination of deer herbivory, invasive plants, and nonnative earthworms, although they suggested that earthworms are the driving factor to these declines. More research is needed on this topic, including synergistic effects, although the negative impacts of all three of these factors to forests are widely accepted at this point.

In addition to direct effects from browsing, Habeck (1960) found that winter deer activity has a marked influence on the physical properties of white cedar swamp soils (soil compaction, peat decomposition, and reduced soil water retention capacity). Habeck's data supported the idea that white cedar swamps in northern Wisconsin, which are subject to **deer yarding** activity, were tending to become drier and less moist. He concluded that changes in the understory vegetation were closely related to soil modifications.

Impacts on Woody Plants

The most direct impact deer have on trees is the prevention of certain species from regenerating (Waller et al. 1996, Alverson and Waller 1997, Rooney et al. 2002). Deer damage to forest regeneration and forest ecosystems has been in evidence since at least the 1930s. Browsing by an overabundant deer population can cause tree regeneration failures, change forest composition, eliminate habitat niches, increase forest regeneration costs, and reduce timber productivity. Deer have a larger effect on survival of seedlings and saplings than the rate at which seeds become seedlings (Waller et al. 1996, Alverson and Waller 1997, Russell et al. 2001, Rooney et al. 2002). Both the Wisconsin and Michigan Society of Foresters have released statements acknowledging the threat that current deer populations pose to the ability to conduct sustainable forestry. The Wisconsin Council on Forestry, appointed by the governor, issued a similar statement in 2007.

Deer prefer certain plant species for food, depending on the time of year and abundance, distribution, and availability of the food source (Dahlberg and Guettinger 1956, Rogers et al. 1981), and avoid others, such as American beech, ironwood (*Ostrya virginiana*), and black cherry (*Prunus serotina*). However, when preferred plant species aren't available, deer will eat almost any plant, including those that aren't palatable or nutritious (VanderZouwen and Warnke 1995). Tree species preferred by deer include northern white-cedar, eastern hemlock, American basswood (*Tilia americana*), eastern white pine (*Pinus strobus*), yellow birch (*Betula alleghaniensis*), sugar maple (*Acer saccharum*), red maple (*A. rubrum*), aspens (*Populus tremuloides*, *P. grandidentata*), oaks, and white ash (*Fraxinus americana*). Preferred shrubs include Canada yew (*Taxus canadensis*), brambles, mountain maple (*Acer spicatum*), dogwoods (*Cornus* spp.), and hazelnut (*Corylus americana* and *C. cornuta*). Species most sensitive to browsing include northern white-cedar, eastern hemlock, yellow birch, northern red oak (*Quercus rubra*),

and Canada yew; in many parts of the state, these species are regenerating sporadically, if at all.

Conifers (northern white-cedar, eastern hemlock, and Canada yew) can be heavily impacted by excessive browse on winter deer range, particularly in the north. Aspens are a highly preferred deciduous species, but they are not usually significantly impacted, due to rapid growth and high stem density, except under continuous high local concentrations of deer (VanderZouwen and Warnke 1995). Other more shade-tolerant deciduous species, such as yellow birch, can be severely affected on both winter and summer ranges. Gill (1992a, 1992b) provided extensive review of deer effects for northern temperate forests.

Deer browsing of forest vegetation can alter community composition and structure, change habitat, and reduce or eliminate populations of plants and animals. Overabundant populations of deer have been correlated with a decline in density of native plant species over the past 50 years (Rooney et al. 2004). Frelich and Lorimer (1985) reported that heavy deer browsing in a wintering site along Lake Superior in Upper Michigan shifted dominant species composition from hemlock to sugar maple. Tilghman (1989) reported a shift from blackberries to ferns at high deer densities in Pennsylvania. The increased abundance of ferns prevented some tree species from regenerating, resulting in a shift in the understory (and ultimately, the overstory) composition.

In addition to directly affecting vegetation, deer browse can have other indirect effects through ecosystem interactions and feedbacks (VanderZouwen and Warnke 1995). These relationships are not well understood but may have greater long-term consequences than the short-term, direct effects. Browse-induced changes to tree species composition can alter forest leaf litter quantity and quality, affecting soil processes and nutrient availability such as the form and amount of nitrogen (NH_4 versus NO_3). These effects can change forest productivity and plant composition (Pastor et al. 1984, Mladenoff 1987). These relationships were demonstrated for moose (*Alces alces*) in the northern portion of the Great Lake states (Pastor et al. 1988, Pastor and Mladenoff 1992) but have yet to be clearly shown for deer (VanderZouwen and Warnke 1995).

Potential Spread of Invasive Species

Heavy deer herbivory can be associated with the invasion and spread of invasive plant species including garlic mustard, exotic buckthorns, and exotic honeysuckles (Waller et al. 2009). Most invasive species that thrive within the range of white-tailed deer have a common trait: the ability to tolerate or resist white-tailed deer herbivory. Garlic mustard and exotic buckthorn, among the most invasive species in the Great Lake states, are typically avoided by deer. Selectively foraging on native plants and not on these invasive species can provide invasives an even greater competitive advantage. However, the impacts of deer browsing are dependent on plant density as well as deer density. Finally, deer can

increase the spread of invasive species by dispersing seeds on their fur or by ingesting mature seeds and ripe fruit and depositing viable seeds in feces (Myers et al. 2004).

Impacts on Birds

Deer affect birds indirectly by browsing vegetation that birds require for nesting cover and foraging and reducing overall structural complexity in their habitats. Studies from the eastern U.S. suggest that deer densities of 15–35 deer per square mile begin to have adverse effects on some bird species. deCalesta (1994) studied the effects of deer densities in Pennsylvania at 10 deer per square mile, 21 per deer square mile, 42 deer per square mile, and 81 deer per square mile. He found a decrease of 27% in the richness of shrub nesting birds from the low to high deer categories and a decrease of 37% in bird abundance. McShea and Rappole (2000) reported that bird population abundance increased when deer were excluded from areas as small as 4 hectares in size in Virginia. In their study, changes in the composition of bird populations corresponded to changes in the density and diversity of understory vegetation when deer density was reduced. High deer densities had negative effects on birds requiring dense understory structures in lowland British woods, mainly by altering food resources and increasing nest losses through predation (Fuller 2001). Insect abundance may be reduced by browsing ungulates (see the “Impacts on Other Species” section below), which could be expected to have negative impacts on breeding birds. Finally, although it is unknown how frequently or widespread it is, deer have been observed

eating eggs and nestlings of ground-nesting grassland bird species (Pietz and Granfors 2000).

The environmental assessment of deer impacts on ecosystems (VanderZouwen and Warnke 1995) reported that shrub-nesting birds would be at greatest risk of impacts from high deer numbers. Wisconsin bird species that may be negatively affected include Black-throated Blue Warbler (*Dendroica caerulescens*), Canada Warbler (*Wilsonia canadensis*), and Swainson's Thrush (*Catharus ustulatus*) in the northern forest region (all three of these species are listed as Wisconsin Special Concern) (VanderZouwen and Warnke 1995, Wisconsin DNR 2005). Species of most concern in southern Wisconsin included Chestnut-sided Warbler (*Dendroica pensylvanica*), Kentucky Warbler (*Oporornis formosus*) (Wisconsin Threatened), Hooded Warbler (*Wilsonia citrina*) (Wisconsin Threatened), and Veery (*Catharus fuscescens*) (VanderZouwen and Warnke 1995). Deer density goals in the few remaining large blocks of forested lands (especially uplands) in southern Wisconsin, such as the Baraboo Hills, Lower Wisconsin State Riverway, and Kettle Moraine State Forest, should consider the potential for negative effects of deer on birds.

Impacts on Other Species

A 1995 environmental assessment of deer impacts on ecosystems by the Wisconsin DNR (VanderZouwen and Warnke 1995) found little information suggesting how invertebrates are affected by different white-tailed deer densities. Reduction of a plant species that supports a host-specific invertebrate population by deer browsing might be expected to cause a reduction in the population of that invertebrate. Also, changes to the understory could lead to changes in litter quality of the forest floor and affect invertebrate populations. One island study (Haida Gwaii, British Columbia) found significant browsing effects on invertebrate abundance and diversity on islands where Sitka black-tailed deer (*Odocoileus hemionus sitkensis*) had been introduced, with changes most apparent in vegetation-dwelling invertebrates (Allombert et al. 2005).

Little information on deer effects on herptiles was found in the 1995 DNR environmental assessment (VanderZouwen and Warnke 1995). By inference, deer could modify the habitat structure needed by specific herptiles or change the food base (invertebrates) for herptile species. Thirty-eight herptiles (14 rare; e.g., ornate box turtle [*Terrapene ornata*], gophersnake [*Pituophis catenifer*], gray ratsnake [*Pantherophis spiloides*], and prairie ring-necked snake [*Diadophis punctatis arnyi*]) occur in the same habitats as white-tailed deer. However, there is no direct evidence that these species are being affected by deer herbivory.

The 1995 environmental assessment (VanderZouwen and Warnke 1995) also found no direct relationship between deer densities and the abundance or diversity of small mammals. However, deer may impact small mammals as direct competition for food (mast crops) and by altering their habi-



Veery nest, Washburn County. This bird Species of Greatest Conservation Need uses thick, deciduous undergrowth, and its habitat could be negatively impacted by heavy deer browse. Photo by Brian Collins.

tat (e.g., shrubs and litter layer) and food base (e.g., seeds) by changing plant composition and structure.

Deer can have an impact on other ungulate species and on predators that prey on them. A portion of the deer herd in southern Wisconsin now has chronic wasting disease, which, if the disease continues to expand northward, could infect elk (*Cervus elaphus*) or moose. In the fall of 2011, chronic wasting disease was found in a wild deer in northwestern Wisconsin (Washburn County), much closer to elk and moose populations. High deer populations provide a food source that supports an expanding gray wolf (*Canis lupus*) population in northern and central Wisconsin.

Socioeconomic Impacts

Deer, especially in high numbers, can have negative social and economic impacts. The following text discusses the impacts that deer overabundance can have on agricultural crops, forests regeneration, urban plants, and public health and safety through deer/vehicle collisions and tick-borne diseases such as Lyme disease.

Agricultural Damage

High deer populations are responsible for 90% of the wildlife crop damage reported in Wisconsin. In 1993 the U.S. Department of Agriculture conducted random damage appraisals in 14 eastern states to determine deer damage to corn crops. Wisconsin was found to have the most severe damage among the states sampled, with corn damage alone estimated at \$15 million. In addition, damage has occurred to Christmas tree farms, orchards, cranberry operations, and other types of crops (Wisconsin DNR 1998).

Wisconsin has had a deer-damage assistance program for agricultural crops since 1931; the most recent program to serve this purpose is the Wildlife Damage Abatement and Claims Program (WDACP). The primary purpose of this program is to provide prevention measures to reduce deer damage to crops. The program also provides compensation for damage, as appraised by a county specialist. From 1994 to 2009, almost \$33 million have been spent to abate or compensate farmers for deer damage (Wisconsin DNR 2010c), which included building almost 278 miles of deer fences. A program that issues shooting permits for deer causing agricultural damage has been in effect since 1987. From 1988 to 2009, over 11,900 deer-damage shooting permits have been issued, and more than 101,500 deer have been killed under these permits.

Forest Damage

Large numbers of deer can affect valuable trees and shrubs. Some foresters have encountered problems regenerating tree species preferred as browse by deer following logging operations due to the browsing of deer on seedlings (Wisconsin DNR 1998). In a 2005 survey of DNR foresters, deer browse was identified as the most significant barrier to success-

ful forest regeneration; 81% of respondents identified deer browse as a problem (Wisconsin Council on Forestry 2005). In 2006 an assessment was made of 51 mixed hardwood-conifer Conservation Reserve Program plantations. In many plantations, deer browse significantly impacted the growth and survival of hardwood seedlings. Preferential browsing of hardwoods, especially on northern red oak, resulted in many plantations being dominated by conifers with an overall low stocking rate (Wisconsin Council on Forestry 2006b).

Consistently sustained overabundant deer populations can significantly impact the practice of sustainable forestry, causing ecological and economic losses. In a 2006 survey, foresters were asked a broad array of questions regarding oak regeneration (Wisconsin Council on Forestry 2006a). One question addressed deer browsing: "If the desired stocking of established natural oak regeneration was not achieved, what factors do you think contributed to the failure?" Respondents were asked to evaluate eight different factors and to rank each from "little or no contribution" to "very strong contribution." Of the eight factors, more respondents identified deer as a strong to very strong contributor to oak regeneration failure than any other factor (Wisconsin Council on



Christmas tree damage from deer browsing. Photo by Wisconsin DNR staff.

Forestry 2006a). Rooney and Waller (2003) found northern red oak seedling densities dropped precipitously as deer browse pressure increased from low to intermediate levels, indicating that red oak regeneration is strongly affected by deer.

Expensive and labor-intensive techniques are sometimes needed to prevent deer damage. Some Christmas tree farmers have resorted to high-priced electric fencing to protect their trees. Landowners trying to establish stands of trees sometimes resort to tree tubes and other expensive methods to help seedlings survive where large deer herds exist. Eastern hemlock, northern white-cedar, and yellow birch provide important wildlife habitat; however, regeneration of these species is highly problematic in areas where deer populations are high. Pines (*Pinus* spp.) and oaks, which are also important to many wildlife species as well as for their timber values, are also difficult to regenerate with high deer densities. In recent years, deer-proof fences have been utilized to protect forest regeneration on public lands in northern Wisconsin. Two fenced exclosures (ranging in size from 29 to 50 acres) have been installed in Bayfield County where deer herbivory led to regeneration failures in harvested stands.

Vehicle-Deer Collisions

Vehicle-deer collisions result in millions of dollars in personal and property damage each year in Wisconsin (VanderZouwen and Warnke 1995). Accurate counts of total vehicle-deer collisions are not possible because not all deer carcasses are found and removed from roadways. Some deer continue to travel after being struck and later die away from the road. Carcass pick-up decreases when gas prices are high and budgets are reduced. The number of reports by county sheriff departments may change due to policy changes. Some vehicle-deer crashes cause little property damage, and in those instances, accident reports are not filed with the Wisconsin Department of Transportation. Despite these shortcomings, the Wisconsin DNR records of carcass disposal provide a minimum estimate of the number of deer hit by vehicles and provide approximate trends in the number of vehicle-deer collisions.

Over 45,000 vehicle-deer accidents have occurred per year during the last decade (Figure 5.3); deer are the third most common item struck by vehicles in Wisconsin. In 2010, 14 people died in vehicle-deer crashes in Wisconsin. In addition, 65 people suffered incapacitating injuries, 204 had less serious injuries, and 120 people were possibly injured (Wisconsin DOT 2010). The number of vehicle-deer accidents has declined some

in the last several years. Combined property damage and personal injury from deer-vehicle accidents was estimated in 1997 to be over \$100 million per year (Wisconsin DNR 1998).

Increases in both deer densities and traffic volume (as well as other factors) result in more vehicle-deer collisions. Decreasing deer population goals would be expected to result in reductions in vehicle-deer collisions. Areas of high deer population densities and high vehicle traffic typically experience the highest levels of collisions. Risk of vehicle-deer crashes has not been reduced by vehicle mounted whistles, roadside reflectors, or fencing. Reducing deer numbers is the only efficient method of reducing vehicle-deer collisions without reducing the number of vehicle miles traveled (VanderZouwen and Warnke 1995).

Damage to Urban Plants

Homeowners in both rural and suburban settings often complain about deer eating their landscaping plants as well as their gardens. Deer will browse trees and shrubs planted for windbreaks, screens between neighbors, backyard wildlife habitat, and scenic beauty. They will often eat flowers, if not whole plants, in annual and perennial gardens.

At the Fairy Chasm Nature Preserve, located in the City of Mequon in southeast Ozaukee County, it has been reported that high deer densities have totally eliminated the wildflower community (the ground layer) over the last 10 years, which once numbered 36 species (VanderZouwen and Warnke 1995). Similar elimination of the wildflower community has been observed at the Schlitz Audubon Nature Center in Milwaukee County. Also in Milwaukee County, deer have caused extensive damage to flower displays at the Boerner Botanical Gardens.

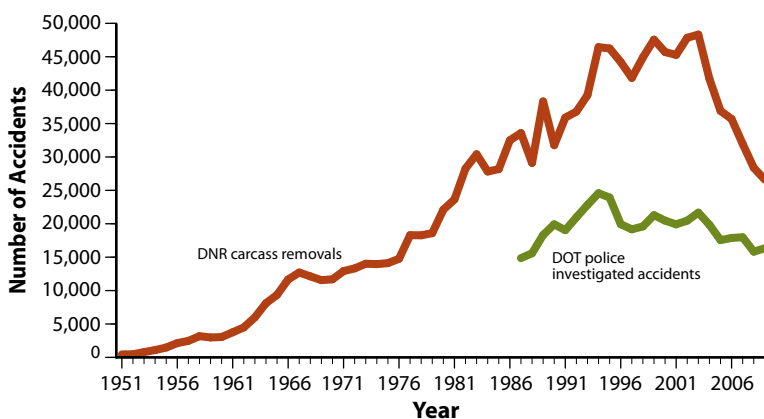


Figure 5.3. Deer-vehicle accidents in Wisconsin, 1950–2006.

Lyme Disease

High incidence of Lyme disease has been associated with deer overabundance (Kilpatrick and LaBonte 2007), and reports of Lyme disease have steadily increased over the past two decades (Figure 5.4). Larval and nymph stages of the deer tick feed on both birds and mammals. However, the adult tick requires a blood meal from a medium to large mammal to reproduce. Deer are the primary host of the adult deer tick. Numerous studies have shown a relationship between the abundance and distribution of deer and deer ticks. However, the threshold at which deer densities need to be reduced to reduce the transmis-

sion rate of Lyme disease to humans is unknown. One study in Mumford Cove, Connecticut, reduced the deer herd by 74%, to 10 deer per square mile, which resulted in an 83% reduction of Lyme disease cases in humans. Although the relationship among deer densities and the incidence of Lyme disease among humans is complex, deer population management may be an important tool to reduce the incidence of Lyme disease among humans. In addition, the reduction of Lyme disease in pets and other domestic animals may be realized. This could be an important issue in Wisconsin where the prevalence of Lyme disease in dogs (10.2%) is more than double that of midwestern (4.0%) and national (5.1%) averages (Bowman et al. 2009).

Deer Population Changes

To understand the impacts of deer on ecosystems today, we need to understand the history of deer populations in Wisconsin. Although white-tailed deer were found throughout the state at the time of Euro-American settlement (Schorger 1953), northern and southern Wisconsin deer populations are treated separately because of the differences in climate, vegetation patterns, and ecosystem types.

Northern Wisconsin

Deer abundance in northern Wisconsin has varied considerably in postglacial times. At the time of Euro-American settlement, northern Wisconsin was primarily mature coniferous-deciduous forest and marginal deer habitat. This marginal habitat, along with severe winters, large predators, and American Indian subsistence hunting, limited the deer population, and they were formerly less abundant than in recent decades. However, the present abundance of deer in northern Wisconsin is certainly less now than it was during the middle of the 20th century (1930–40s) (Bersing 1966, McCaffery 1995), following the Cutover and early regeneration of northern forests. See Craven and Van Deelen (2008) for more details.

Records of deer abundance during the time of Euro-American settlement are fragmentary (Swift 1946, Schorger 1953, Christensen 1959, McCaffery 1995). Dahlberg and Guettinger (1956) attempted to schematically depict the relative abundance of deer from 1750 to 1955 (Figure 5.5). It is possible that the average density of deer may have approached 10–15 deer per square mile in the area of the present northern

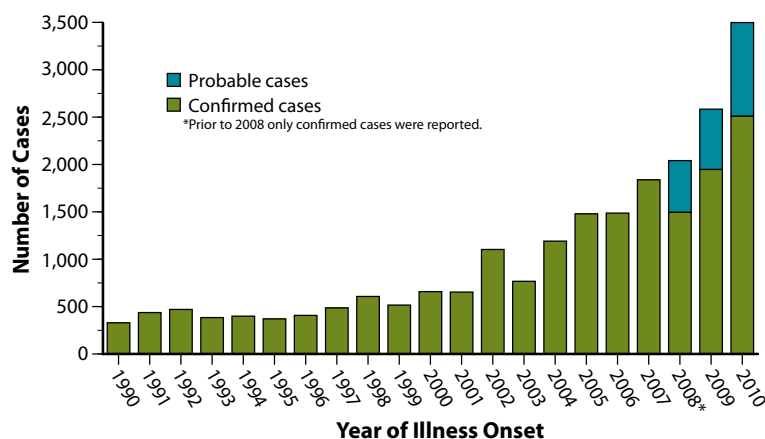


Figure 5.4. Incidence of Lyme disease in Wisconsin, 1990–2009. Data from Wisconsin Department of Health Services (2010).

forest prior to 1800. A study using archeological, anthropological, and historical data (McCabe and McCabe 1997) and another using a habitat model (Alverson et al. 1988) provided estimates of 5–10 and 8–11 deer per square mile, respectively, for portions of the white-tailed deer range.

The deer population increased and expanded in northern Wisconsin after large-scale logging began in the late 1800s (Schorger 1953). The former mature, mixed conifer-hardwood forest in northern Wisconsin was eventually replaced by young hardwoods, including vast acreages of aspen and white birch (*Betula papyrifera*) and other forage plants that provided an abundant food supply for deer. However, the large number of settlers that followed logging depended on venison for food. Subsistence harvest, together with market hunting, likely reduced the state deer population to its lowest level around the beginning of the 20th century.

Hunting regulations began in 1897, but it wasn't until the 1920s that overhunting was curbed. Conservative harvests in the early 1900s along with regrowth of the northern forest permitted deer populations to increase in the north. Deer became abundant in northern Wisconsin by the mid-1900s (see the “Changes to Fauna” section in Chapter 4, “Changes and Trends in Ecosystems and Landscape Features”). As deer populations grew, the impacts of browsing on forest vegetation became apparent. Overwinter starvation of deer was first reported in 1930.

Deer populations were probably at their highest in recent centuries in 1942 or 1943 (Bersing 1966) following extensive logging and fires in northern Wisconsin. The northern deer population was likely in excess of 700,000 in 1943, based on the harvest of bucks. Deer drives from 1935 to 1941 averaged 45 deer per square mile (Swift 1946). In 1938, it was estimated that 89% of the Nicolet National Forest had been clearcut and/or burned, with only 11% left in commercial-size trees. This condition was probably representative of most of the area of the northern forest (USFS 1988), which would have been prime summer deer range. Large-scale winter feeding was done from 1934 through 1954 in an effort to prevent starvation of deer. Failure of this feeding program led to the institution of antlerless deer harvests to control and reduce the size of the deer herd.

Habitat today is different from habitats at the time of Euro-American settlement and after the post-logging era. Forests have regrown and partially recovered from the widespread, intensive, and destructive logging of the Cutover. Forests continue to age and succeed to more shade-tolerant types, but large acreages of aspen have been maintained for pulp

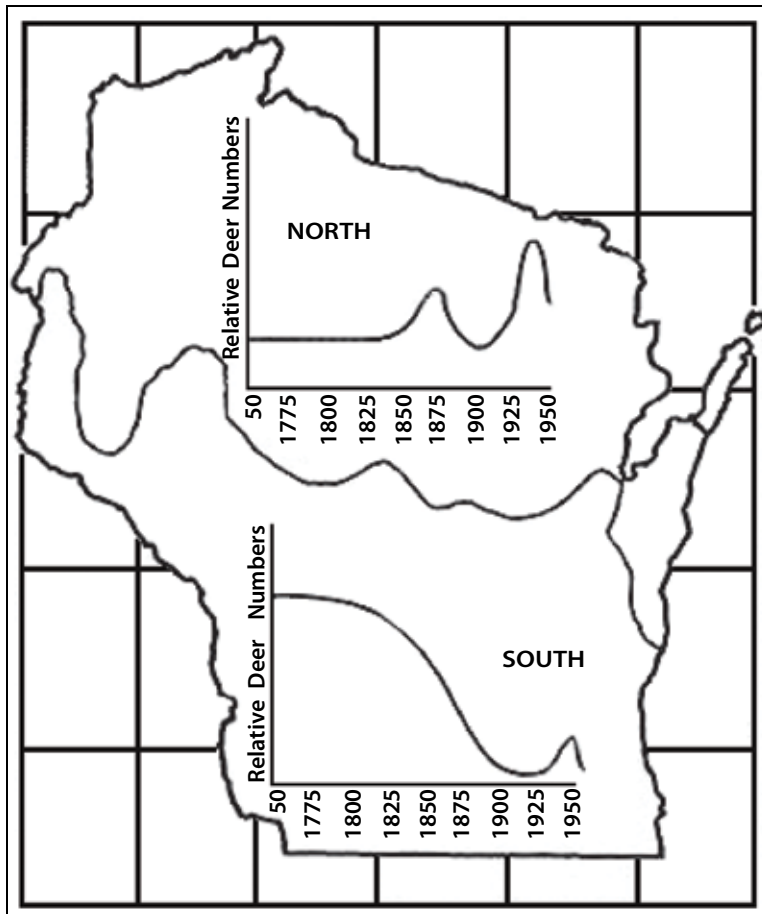


Figure 5.5. Relative deer numbers from 1750 to 1950. Figure reproduced from Dahlberg and Guettinger (1956).

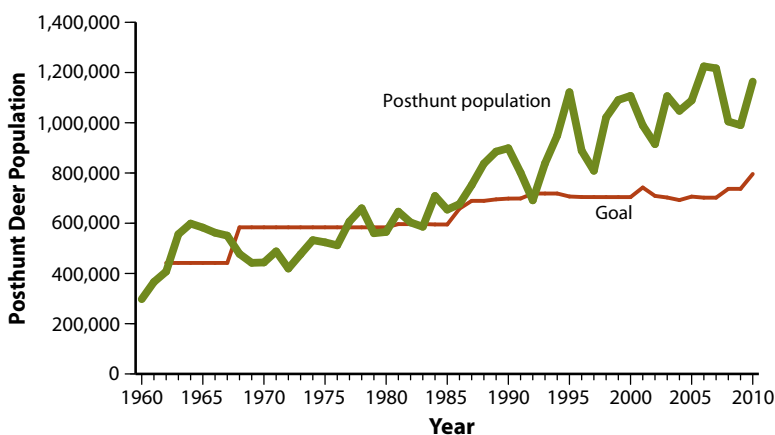


Figure 5.6. Statewide deer populations in relation to deer management goals, 1961–2009.

production and to benefit species associated with early successional habitats. However, the deer carrying capacity of the forest has been reduced from the 1940s, when almost the entire north was in early successional forest. Since 1962, deer populations have been managed using a hunting quota system allowing the harvest of female deer to keep deer popula-

tions in check. Populations ranged from a low of fewer than 200,000 deer in 1972 following a sequence of severe winters to more than 400,000 deer in 1990 and 1991 after a decade of mild winters (VanderZouwen and Warnke 1995). These recent deer population changes have been driven by hunting harvest quotas and severity of winter weather, which affects deer energy demand, deer movement, overwinter survival, and recruitment rates the following spring.

Southern Wisconsin

The same lack of data exists for deer populations in southern Wisconsin prior to Euro-American settlement. Generally, deer were more abundant in southern Wisconsin than in northern Wisconsin prior to Euro-American settlement (20–50 deer per square mile) (Dahlberg and Guettinger 1956). However, the deer population declined to very low numbers after Wisconsin was settled as a result of subsistence hunting, professional market hunters sending tons of venison to the large eastern cities, and conversion of land from hardwood forest, savanna, and prairie to agriculture. The deer population in southern Wisconsin was likely reduced to its lowest level late in the 19th century. Deer population numbers remained low in southern Wisconsin until the late 1960s/early 1970s when deer populations began to increase (see the “Changes to Fauna” section in Chapter 4) (VanderZouwen and Warnke 1995). Since the early 1980s, deer populations have increased dramatically in southern Wisconsin. By 1995, deer populations in southern Wisconsin were at record numbers for the century and have remained high through the 2000s. Deer are using a mix of agricultural crops, wetlands, and woodlands as habitat as well as urban areas, nature preserves, and parks, causing damage to shrubs and trees in these areas.

Current Populations

The statewide deer population greatly increased in the 1980s (Figure 5.6) and has remained at historically unprecedented levels and above goals for most of the last 30 years. These high deer numbers cause significant negative impacts to browse-sensitive plants, forest regeneration, agriculture, urban vegetation, and the practice of sustainable forestry. Only in the time period 2008–2011 have deer populations been reduced somewhat in northern deer management units; however, many deer management units are still above goals. For a discussion of how deer are

and have been managed in Wisconsin, see *Wisconsin's Deer Management Program: the Issues Involved in Decision Making* (Wisconsin DNR 1998).

Currently, information is lacking on what the size of deer populations can be to both provide recreational opportunities and sustain all of Wisconsin's ecosystems. Lack of tree regeneration and elimination of browse-sensitive plants indicate that deer herds may currently be too high in some areas. In addition, methods on how to measure the acceptable amount of browse pressure that will allow ecosystems to sustain themselves are needed. Research to answer some of these questions began in 2010.

Bioenergy

Sources of renewable energy, including biomass derived from forests and various agricultural products, are receiving increased attention because of projected shortages of petroleum fuels, rising energy prices, and climate change concerns. Society's current reliance on fossil fuels is not sustainable, but there are concerns about the impacts of increased removals of material from ecological systems to produce renewable energy as well as questions about net energy balances, economic factors, and social effects. Wisconsin outlined a plan to generate 25% of the state's electricity and transportation fuel from renewable sources by 2025, primarily through large increases in the amount of land from which biofuels could be derived (UWEX Center for Land Use Education 2007, 2008, 2009). Generating renewable energy on large scales will require some dramatic changes to the state's ecosystems and the way land is currently used. It is projected that if Wisconsin citizens maintain the same energy growth rate in the future (approximately a 2% increase in energy use per year), 46% of Wisconsin's land would need to be devoted to renewable energy production to meet the renewable energy goal in 2025.

Use of bioenergy is sometimes viewed as a way to mitigate climate change through the reduction of CO₂ emissions, but this relies on an assumption of carbon neutrality—that CO₂ released from the use of plant-based biomass is taken up at once by other plants. Another analytical approach adjusts the carbon debt over the years taken to regrow the plant material; this approach can show a high degree of variability in the time required to reach carbon neutrality depending on the technologies used and the types of fuel that are replaced by bioenergy (MCCS 2010). Life cycle analyses are needed whenever bioenergy projects are proposed to determine whether the projects will realize an energy gain and/or a net carbon reduction.

Another fundamental consideration in the use of bioenergy feedstocks is whether they can provide a net energy gain. If more energy is used in growing, harvesting, transporting, processing, and delivering biomass feedstocks than the bioenergy produced, the practice is neither effective in achieving energy independence nor in mitigating climate

change. Much controversy still surrounds whether ethanol has a positive net energy balance or whether it takes more energy to produce than it provides, depending on the starting point of the analysis and whether a complete life cycle analysis is used. Pimentel (2003) reported that growing corn for ethanol used more energy than is produced. Another study found that ethanol produced 34% more energy than it took to grow, harvest, transport, and make it (Shapouri et al. 2002). Additional analyses such as these are needed to ensure that a renewable energy source has a positive net energy gain.

There are both socioeconomic and ecological trade-offs related to the increased use of bioenergy in Wisconsin. For example, employment in secondary wood processing may decline as woody material is used for energy, and the pulp industry may be impacted as it competes with bioenergy markets for wood supplies. In addition, the growth and harvest of products for bioenergy production can lead to the simplification or conversion of natural ecosystems as well as impact wildlife habitat. Indirect impacts of wood or agriculturally derived bioenergy may also include changes in land use that can affect food supplies. For example, growing corn for ethanol production uses acres that could be used for growing food for people. If the 2025 goal is to be met, over 41% of the land that is used to grow corn in Wisconsin (2.9 million acres) would need to be devoted to ethanol production rather than food production (UWEX Center for Land Use Education 2007, 2008, 2009). Finally, the use of bioenergy may increase the demand for wood and have other wide-ranging impacts that may be seen in global wood markets and rates of deforestation.

Forest and Woody Biomass Issues

Harvesting woody biomass is an option being considered to meet renewable energy goals in Wisconsin. If all of Wisconsin's energy consumption (1,862 trillion BTUs in 2008, according to the U.S. Energy Information Administration) was to be supplied by forests, approximately 3 million acres would be needed annually, and forests would be completely gone in six years. (Wood supply figures were calculated using 2007 data available from the Forest Inventory and Analysis National Program, U.S. Forest Service.) Energy conversions use an average value of 8,600 BTUs per pound of bone-dry wood (BFIN 2010). Logging residues (tree tops and unusable material left after harvests) are estimated to be between 609,000 and 2,325,000 dry tons annually, based on four studies reported in Willyard and Tikalsky (2006). If two-thirds of the average of this estimated amount could be collected (1,092,255 dry tons per year), it would represent about 1% of total energy consumption in the state. These are maximum estimates; actual availability depends on economics, landowner willingness, and other factors, so the amount available could be substantially less.

Dead wood and other plant materials commonly targeted for biomass harvest have important roles in ecological func-

tion. A relatively large proportion of a tree's nutrients are contained in branches and twigs, and removing fine wood alters nutrient cycling in forested ecosystems. Nitrogen and phosphorous, in forms available to plants, are primarily supplied from these and other decomposing organic materials. Dead wood provides sites for nitrogen fixation, and when decomposed, it enhances soil properties such as aeration and moisture holding capacity. Dead wood also represents a carbon storage component that can help keep CO₂ out of the atmosphere and mitigate climate change. Wildlife can be affected by the removal of woody debris because many species utilize it for shelter and foraging. It is unclear how much dead wood is critical to maintaining ecosystem processes or what would be required to rehabilitate a site that had become nutrient depleted or had lost other essential functions. Most forested ecosystems in the state are likely to contain much lower amounts of dead woody material than the forests that were present at the time of Euro-American settlement. More research is needed to identify threshold amounts of woody debris needed to support ecosystem functions. A field manual has been developed for Wisconsin using currently available data to provide guidelines regarding the harvest of woody biomass (Herrick et al. 2009).

Harvesting additional wood from a site for bioenergy production may have other important ecological impacts as well. A second biomass harvest occurring after the initial timber harvest has taken place will require additional equipment in forests. This has the potential to increase soil compaction, take areas out of production for roads and landings, wound residual trees, introduce invasive species, and disturb both wildlife and flora.

Because of concerns for environmental impacts and the inadequacy of woody biomass supplies from natural forests in Wisconsin as indicated by the above calculations, bioenergy plantations are being considered as a substitute source of wood for the state. Fast-growing species like hybrid poplar (*Populus x canadensis*) and black willow (*Salix nigra*) are typically grown for energy production on very short rotations (e.g., five years). The practice is considered **agroforestry** and requires intensive cultivation techniques, including fertilization and herbicides. There is a need to develop agroforestry methods that are sustainable, less costly, and require fewer high energy inputs. In addition, **short-rotation plantations** are very simplified ecosystems with potentially significant negative implications for biodiversity, depending on what existing habitats they replace. These implications can manifest themselves at a variety of scales including landscape-level—for example, the fragmentation of grasslands by siting woody plantations in open, grass-dominated landscapes) (Paine et al. 1996).

Use of woody biomass as an energy source may help reduce energy reliance on fossil fuels, but its use should be carefully evaluated at various scales from the site level to landscape scale to ensure that it results in a net energy gain, is carbon neutral, and has minimal impact on wildlife habi-

tat and ecosystems as a whole, including the ecological processes needed to sustain them into the future.

Agriculture Bioenergy

Agricultural products used to produce energy include those, such as corn and soybeans, that can be converted to liquid fuels (ethanol or biodiesel) as well as those that can be burned, typically along with another fuel, to produce heat or electricity. Most agricultural material has a low bulk density (low number of BTUs per pound) and is expensive to transport. With current technology, careful attention is needed to evaluate whether projects are cost effective and represent a net energy gain. For example, growing corn for ethanol or soybeans for biodiesel requires inputs of chemical fertilizers, herbicides, pesticides, and additional fossil fuels to plant, cultivate, harvest, and transport the crop to a processing plant. In addition, ethanol processing plants can use large amounts of water to produce the fuel, causing a strain on groundwater reservoirs and problems with disposing of the effluent. Using corn and soybeans for energy production rather than food has also raised concerns about increasing food costs and decreasing global food supplies.

The expansion of a bioenergy industry based on grass and other nonwoody materials (e.g., corn **stover**) has the potential to impact land use at a large scale in Wisconsin, primarily in the regions of the state currently dominated by agriculture. While the impacts will be most concentrated within the **fuelshed** of an individual biomass plant, proliferation of new plants across the landscape could result in significant land use conversion on a larger scale if areas currently dedicated to other uses (e.g., Conservation Reserve Program lands) are converted to agricultural production.

An expansion of grass bioenergy feedstocks has the potential to benefit the state's soil, water quality, and wildlife habitats by transforming annual agricultural crops to more perennial crops. Conversely, expansion of the acreage in the state planted to row crops for the harvest of corn stover or corn for ethanol would have negative environmental impacts on most ecosystem services. Regardless of the feedstock produced, Wisconsin's agricultural sector could benefit economically in the short term from increased markets for agricultural products, creating jobs and reducing reliance on nonrenewable fuels. Long-term benefits and sustainability of nonwoody biomass harvest is more uncertain and may depend on improved technologies.

Large-scale nonwoody bioenergy production could have significant effects for conservation. Grassland-dependant wildlife has been disappearing from the Wisconsin landscape, and many of these species, including grassland birds, are of high conservation concern as a result. For example, the recent increase in corn acreage grown for ethanol production has been accompanied by a reduction in grasslands enrolled in the Conservation Reserve Program (CRP) (Secchi 2007, Searchinger et al. 2008). The reduction in CRP lands

has decreased the available grassland habitat for grassland birds by 35%–40% (D. Sample, Wisconsin DNR, personal communication) (Figure 5.7). We know that corn is poor wildlife habitat in general, and perennial grass habitats are higher in grassland bird diversity and density than in row crops (Paine et al. 1996). Research has shown that switchgrass fields harvested for bioenergy are used by many grassland bird species (Roth et al. 2005). Further, diversity of grassland birds is higher in diverse mixes of native grasses and forbs (e.g., prairie restorations) than in the monocultures that might be grown as a bioenergy crop (e.g., monotypic switchgrass). Research is currently assessing nesting productivity along a gradient of plant species diversity (e.g., switchgrass monotypes compared to prairie restorations) in Wisconsin to evaluate how an increase in grass crops grown for bioenergy may impact grassland bird populations.

Understanding the potential impacts and assuring that the production of nonwoody biomass is done within the framework of sustainable resource management is a priority of the Wisconsin DNR and the Wisconsin Department of Agriculture, Trade and Consumer Protection. While delaying harvest of grass-based bioenergy crops until after the breeding season may reduce take of grassland bird species, long-term impacts of land use conversion on erosion and wildlife habitat are more difficult to evaluate. Science-based guidelines for nonwoody biomass planting and harvesting in Wisconsin were developed to help ensure the sustainability of, and provide benefits to, the natural resources of the state (Hull et al. 2011).

The bioenergy arena is currently very dynamic; consequently, guidelines or best management practices will need to be adaptable as new information becomes available. Guidelines take a precautionary approach, helping ensure that biomass planting and harvesting does not degrade ecosystems or make them unsustainable, given the uncertainty of our current understanding of many aspects of bioenergy use and development and the potential for harm to sensitive species and ecosystems. The recommendations and guidelines for growing and harvesting of nonwoody biomass reflect the following principles:

- Maintenance and improvement of soil quality by minimizing erosion, enhancing carbon sequestration, promoting healthy biological systems, and protecting chemical and physical properties

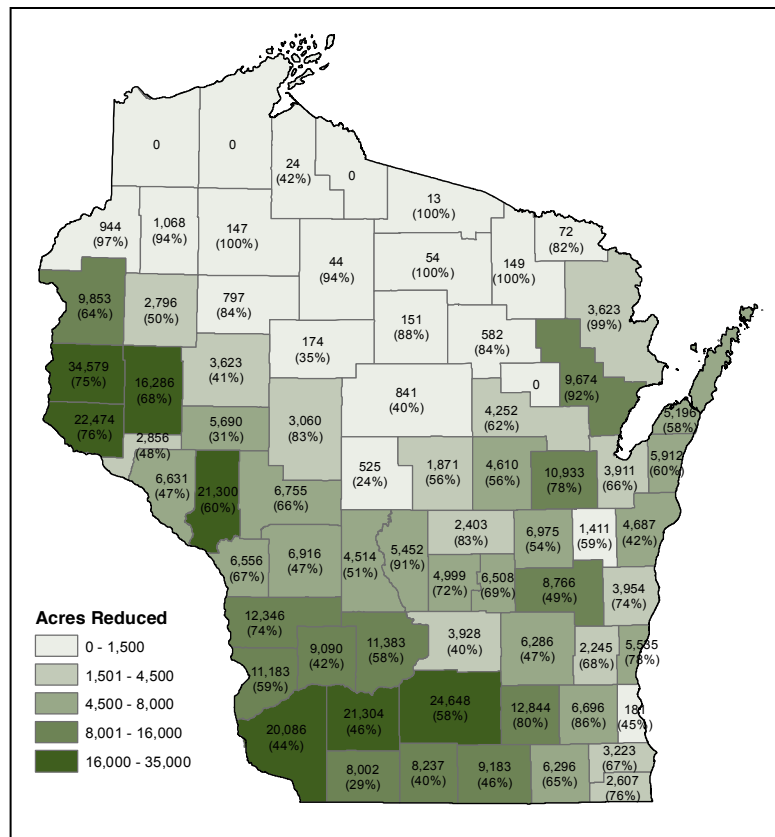


Figure 5.7. Reduction in acreage of Conservation Reserve Program (CRP) lands in Wisconsin as of October 2012. Values shown are the reduction in CRP acres for each county from their highest reported acreage from 1986 through 2012. Values in parentheses are the percent reduction from the maximum during this period. Statewide, CRP acreage is less than half of what it was at its highest point. Data were provided by Scott Walter, Wisconsin DNR.

- Maintenance and improvement of the quality and quantity of surface waters, groundwater, and aquatic ecosystems
- Maintenance and improvement of the quality and quantity of habitat for fish and wildlife species, including rare, declining, and endangered species
- Conservation and enhancement of biological diversity, in particular native plants, insects, and wildlife by avoiding the conversion of native habitats to energy crop production and introduction of invasive or nonnative species
- Utilization (or promotion) of sustainable agricultural practices that enhance ecosystem services
- Consideration of the impact of biomass programs on landscape-scale land use changes and ecosystem services

Agricultural bioenergy may be an important tool to help reduce energy reliance on fossil fuels, but thorough life cycle analyses need to be done to ensure that the production of energy from agricultural bioenergy actually reduces energy consumption, is carbon neutral, and does not further degrade ecosystems and/or make them unsustainable in the long term.

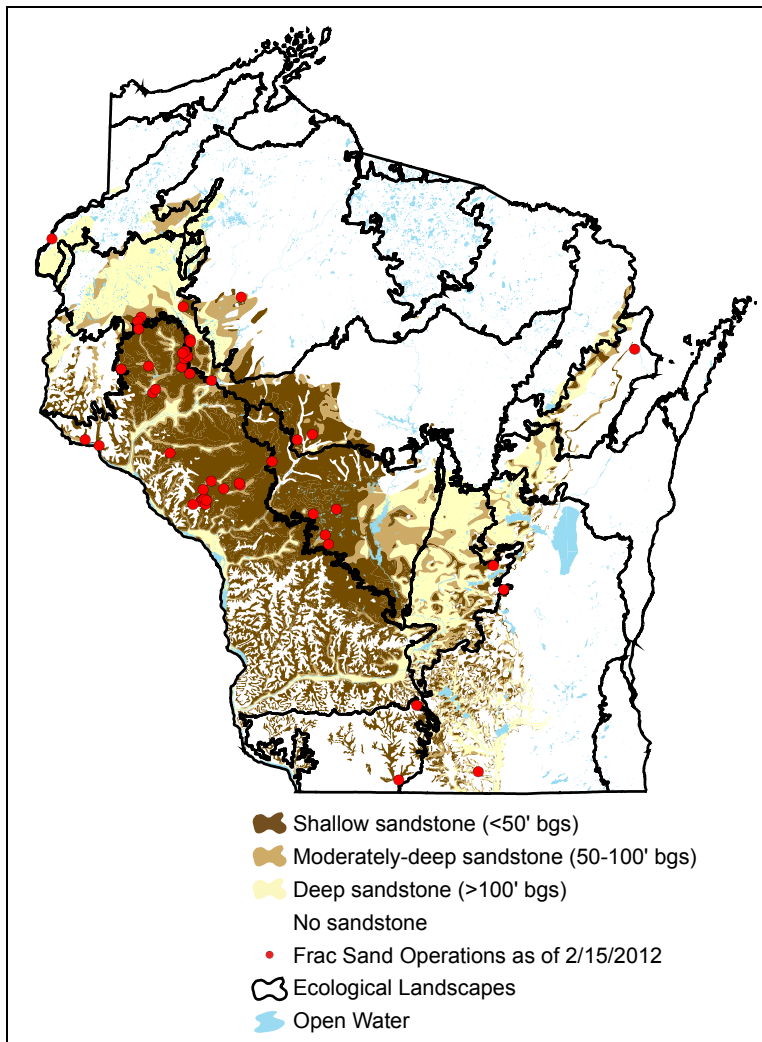


Figure 5.8. Frac sand potential in Wisconsin (WGNHS 2012). (Below ground surface, bbs).



Frac sand operation near Bloomer, Chippewa County. Photo by Mary Kenosian.

Sand Mining

Wisconsin, at the time of this writing, is seeing a dramatic increase in the number of sand mines. Wisconsin contains high-quality sand resources that are used in hydraulic fracturing, or *hydrofracking*, a technique used by the petroleum industry to extract natural gas and/or crude oil from rock formations. Hydrofracking has been in use for several decades, but recent technological developments have made it possible to extract natural gas and oil that was previously unattainable. Also, it is now economically feasible to mine formations that had previously been deemed too expensive.

Although Wisconsin contains no major shale gas resources, it features some of the best “frac sand” resources in the country. Sand mined in Wisconsin is sent to locations as far away as Texas. Sands used for hydrofracking should be nearly pure quartz, very well rounded, meet tight size gradation standards, and have a high compressive strength. These sands are mined from poorly cemented *Cambrian* and *Ordovician sandstones* and from unconsolidated alluvial sands locally derived from these sandstones. Sands derived from Quaternary glacial deposits and most beach and riverbank sands are too impure and too angular to be used as frac sand (Wisconsin DNR 2012c).

Wisconsin sand has been mined for use in the petroleum industry for over 40 years, but the demand has increased exponentially in the past few years. As of January 2012, there were approximately 20 new mining operations being proposed (Wisconsin DNR 2012c) (Figure 5.8). The dramatic increase in these projects presents issues for understanding and controlling the potential impacts of these mines. Concerns have been raised regarding environmental and nuisance problems, and the potential for these issues is not always well understood, especially the cumulative impacts. Rare species and natural communities can often be associated with these sands, and rare species data are typically lacking for private lands since the majority of them have never been surveyed. The range of one rare species, the Federally Endangered Karner blue butterfly (*Lycaeides melissa samuelis*), corresponds to much of the area containing frac sand, and it can sometimes be associated with other much rarer animal and plant species.

Appendix 5.A. Invasive species regulated by [Chapter NR 40](#), Wisconsin Administrative Code.

ALGAE AND CYANOBACTERIA

Prohibited^a:

Cylindro	<i>Cylindrospermopsis raciborskii</i>
Didymo or rock snot	<i>Didymosphenia geminata</i>
Golden alga	<i>Prumneisum parvum</i>
Novel cyanobacterial epiphyte	<i>Ulva</i> spp., <i>Enteromorpha</i> spp., or <i>Stigonematales</i> spp.
of order Stigonematales	
Starry stonewort	<i>Nitellopsis obtusa</i>

AQUATIC PLANTS

Prohibited:

Australian swamp crop	<i>Crassula helmsii</i>
Brazilian waterweed	<i>Egeria densa</i>
Brittle naiad	<i>Najas minor</i>
European frog-bit	<i>Hydrocharis morsus-ranae</i>
Fanwort	<i>Cabomba caroliniana</i>
Hydrilla	<i>Hydrilla verticillata</i>
Oxygen-weed	<i>Lagarosiphon major</i>
Parrot feather	<i>Myriophyllum aquaticum</i>
Water chestnut	<i>Trapa natans</i>
Yellow floating heart	<i>Nymphoides peltata</i>

Restricted^b:

Curly-leaf pondweed	<i>Potamogeton crispus</i>
Eurasian watermilfoil	<i>Myriophyllum spicatum</i>
Flowering rush	<i>Butomus umbellatus</i>

TERRESTRIAL PLANTS

Prohibited:

Chinese yam	<i>Dioscorea oppositifolia</i>
Giant hogweed	<i>Heracleum mantegazzianum</i>
Giant knotweed	<i>Polygonum sachalinense</i>
Japanese honeysuckle	<i>Lonicera japonica</i>
Japanese stilt grass	<i>Microstegium vimineum</i>
Kudzu	<i>Pueraria montana</i> or <i>P. lobata</i>
Mile-a-minute vine	<i>Polygonum perfoliatum</i>
Pale swallow-wort	<i>Vincetoxicum rossicum</i> or <i>Cynachum rossicum</i>
Perennial pepperweed	<i>Lepidium latifolium</i>
Porcelain berry	<i>Ampelopsis brevipedunculata</i>
Princess tree	<i>Paulownia tomentosa</i>
Sawtooth oak	<i>Quercus acutissima</i>
Scotch broom	<i>Cytisus scoparius</i>
Sericea lespedeza	<i>Lespedeza cuneata</i>
Spreading hedgeparsley	<i>Torilis arvensis</i>
Wineberry	<i>Rubus phoenicolasius</i>
Yellow star thistle	<i>Centaurea solstitialis</i>

Prohibited/Restricted:

Amur honeysuckle	<i>Lonicera maackii</i>
Black swallow-wort	<i>Vincetoxicum nigrum</i> or <i>Cynachum louiseae</i>
Celandine	<i>Chelidonium majus</i>
European marsh thistle	<i>Cirsium palustre</i>
Hairy willow herb	<i>Epilobium hirsutum</i>
Hill mustard	<i>Bunias orientalis</i>
Japanese hedgeparsley	<i>Torilis japonica</i>
Japanese hops	<i>Humulus japonicus</i>
Lyme grass	<i>Leymus arenarius</i> or <i>Elymus arenarius</i>
Poison hemlock	<i>Conium maculatum</i>
Tall manna grass	<i>Glyceria maxima</i>
Wild chervil	<i>Anthriscus sylvestris</i>

Appendix 5.A, continued.**Restricted:**

Autumn olive	<i>Elaeagnus umbellatus</i>
Bell's honeysuckle	<i>Lonicera x bella</i>
Canada thistle	<i>Cirsium arvense</i>
Common buckthorn	<i>Rhamnus cathartica</i>
Common teasel	<i>Dipsacus sylvestris</i> or <i>D. fullonum</i>
Creeping bellflower	<i>Campanula rapunculoides</i>
Cut-leaved teasel	<i>Dipsacus laciniatus</i>
Cypress spurge	<i>Euphorbia cyparissias</i>
Dames rocket	<i>Hesperis matronalis</i>
Garlic mustard	<i>Alliaria petiolata</i>
Glossy buckthorn	<i>Rhamnus frangula</i> or <i>Frangula alnus</i> (Asplenifolia and Fineline [Ron Williams] are exempt cultivars.)
Helleborine orchid	<i>Epipactis helleborine</i>
Hemp nettle	<i>Galeopsis tetrahit</i>
Hound's tongue	<i>Cynoglossum officinale</i>
Hybrid cattail	<i>Typha x glauca</i>
Japanese knotweed	<i>Polygonum cuspidatum</i> or <i>Fallopia japonica</i>
Leafy spurge	<i>Euphorbia esula</i>
Morrow's honeysuckle	<i>Lonicera morrowii</i>
Multiflora rose	<i>Rosa multiflora</i>
Musk thistle	<i>Carduus nutans</i>
Narrow-leaf cattail	<i>Typha angustifolia</i>
Oriental bittersweet	<i>Celastrus orbiculatus</i>
Phragmites or common reed	<i>Phragmites australis</i>
Plumeless thistle	<i>Carduus acanthoides</i>
Purple loosestrife	<i>Lythrum salicaria</i>
Russian olive	<i>Elaeagnus angustifolia</i>
Spotted knapweed	<i>Centaurea biebersteinii</i>
Tansy	<i>Tanacetum vulgare</i> (Aureum and Compactum are exempt cultivars.)
Tartarian honeysuckle	<i>Lonicera tatarica</i>
Tree-of-heaven	<i>Ailanthus altissima</i>
Wild parsnip	<i>Pastinaca sativa</i>

FISH AND CRAYFISH**Prohibited:**

Bighead carp	<i>Hypophthalmichthys nobilis</i>
Black carp	<i>Mylopharyngodon piceus</i>
Eastern mosquitofish	<i>Gambusia holbrooki</i>
Grass carp	<i>Ctenopharyngodon idella</i>
Red shiner	<i>Cyprinella lutrensis</i>
Red swamp crayfish	<i>Procambarus clarkii</i>
Rudd	<i>Scardinius erythrophthalmus</i>
Silver carp	<i>Hypophthalmichthys molitrix</i>
Snakehead species	<i>Synbranchidae</i> spp.
Tench	<i>Tinca tinca</i>
Western mosquitofish	<i>Gambusia affinis</i>
Zander	<i>Sander lucioperca</i>

Restricted:

Alewife	<i>Alosa pseudoharengus</i>
Arctic char	<i>Salvelinus alpinus</i>
Atlantic salmon	<i>Salmo salar</i>
Bitterling	<i>Rhodeus</i> spp.
Brown trout	<i>Salmo trutta</i>
Chinese hi-fin banded shark	<i>Myxocyprinus asiaticus</i>
Chinook salmon	<i>Oncorhynchus tshawytscha</i>
Coho salmon	<i>Oncorhynchus kisutch</i>
Common carp	<i>Cyprinus carpio</i>

Continued on next page

Appendix 5.A, continued.

Goldfish	<i>Carassius auratus</i>
Idé	<i>Leuciscus idus</i>
Koi	<i>Cyprinus carpio</i>
Pink salmon	<i>Oncorhynchus gorbuscha</i>
Rainbow smelt	<i>Osmerus mordax</i>
Rainbow trout	<i>Oncorhynchus mykiss</i>
Redear sunfish	<i>Lepomis microlophus</i>
Round goby	<i>Neogobius melanostomus</i>
Ruffe	<i>Gymnocephalus cernuus</i>
Rusty crayfish	<i>Orconectes rusticus</i>
Sea lamprey	<i>Petromyzon marinus</i>
Sterlet	<i>Acipenser ruthenus</i>
Three-spine stickleback	<i>Gasterosteus aculeatus</i>
Tiger trout	A hybrid of <i>Salvelinus fontinalis</i> and <i>Salmo trutta</i>
Tilapia	<i>Tilapia</i> spp.
Tubenose goby	<i>Proterorhinus marmoratus</i>
Weather loach	<i>Misgurnus anguillicaudatus</i>
White perch	<i>Morone americana</i>

AQUATIC INVERTEBRATES EXCEPT CRAYFISH

Prohibited:

Asian clam	<i>Corbicula fluminea</i>
Bloody shrimp	<i>Hemimysis anomala</i>
Chinese mitten crabs	<i>Eriocheir sinensi</i>
Faucet snail	<i>Bithynia tentaculata</i>
Fishhook water flea	<i>Cercopagis pengoi</i>
New Zealand mudsnail	<i>Potamopyrgus antipodarum</i>
Quagga mussel	<i>Dreissena rostriformis</i>
Spiny water flea	<i>Bythotrephes cederstroemi</i>
Water flea	<i>Daphnia lumholtzi</i>

Restricted:

Chinese mystery snail	<i>Cipangopaludina chinensis</i>
Zebra mussel	<i>Dreissena polymorpha</i>

TERRESTRIAL INVERTEBRATES AND PLANT DISEASE-CAUSING MICROORGANISMS

Prohibited:

Asian gypsy moth	<i>Lymantria dispar</i> – Asian race
Asian long-horned beetle	<i>Anoplophora glabripennis</i>
Crazy worm	<i>Amyntas</i> spp. or <i>Amyntus</i> spp.
Emerald ash borer	<i>Agilus planipennis</i>
Hemlock woolly adelgid	<i>Adelges tsugae</i>
Scale associated with beech bark disease	<i>Cryptococcus fagisuga</i>
Sudden oak death pathogen	<i>Phytophthora ramorum</i>

Restricted:

European Gypsy moth	<i>Lymantria dispar</i> – European race
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TERRESTRIAL AND AQUATIC VERTEBRATES EXCEPT FISH

Prohibited:

Feral domestic swine	<i>Sus domestica</i>
Monk, Quaker parakeet or parrot	<i>Myiopsitta monachus</i>
Russian boar	<i>Sus scrofa</i>

Restricted:

Red-eared slider (with a carapace under 4")	<i>Trachemys scripta elegans</i>
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***Prohibited:** Invasive species that are not currently found in Wisconsin, with the exception of small pioneer stands of terrestrial plants and aquatic species that are isolated to a specific watershed in the state or the Great Lakes, but which, if introduced into the state, are likely to survive and spread, potentially causing significant environmental or economic harm or harm to human health.

^b**Restricted:** Invasive species that are already established in the state and cause or have the potential to cause significant environmental or economic harm or harm to human health and includes established nonnative fish and crayfish, fish in the aquaculture trade, fish in the aquarium trade, and nonviable fish species.

Appendix 5.B. *Scientific names of species mentioned in Chapter 5.*

Common Name	Scientific Name
Alewife	<i>Alosa pseudoharengus</i>
American basswood	<i>Tilia americana</i>
American beech	<i>Fagus grandifolia</i>
American hazelnut	<i>Corylus americana</i>
American marten	<i>Martes americana</i>
Annosum root rot fungus	<i>Heterobasidion annosum</i>
Ashes	<i>Fraxinus</i> spp.
Asian carp	
Grass carp	<i>Ctenopharyngodon idella</i>
Silver carp	<i>Hypophthalmichthys molitrix</i>
Bighead carp	<i>H. nobilis</i>
Black carp	<i>Mylopharyngodon piceus</i>
Beaked hazelnut	<i>Corylus cornuta</i>
Beech bark disease fungus	<i>Neonectria</i> spp.
Beech bark disease scale insect	<i>Cryptococcus fagisuga</i>
Bigtooth aspen	<i>Populus grandidentata</i>
Black cherry	<i>Prunus serotina</i>
Black willow	<i>Salix nigra</i>
Black-throated Blue Warbler ^a	<i>Dendroica caerulescens</i>
Brambles	<i>Rubus</i> spp.
Brook trout	<i>Salvelinus fontinalis</i>
Brown trout	<i>Salmo trutta</i>
Butternut canker fungus	<i>Sirococcus clavigignenti-juglandacearum</i>
Canada Warbler	<i>Wilsonia canadensis</i>
Canada yew	<i>Taxus canadensis</i>
Cherries	<i>Prunus</i> spp.
Chestnut-sided Warbler	<i>Dendroica pensylvanica</i>
Chinook salmon	<i>Oncorhynchus tshawytscha</i>
Coho salmon	<i>Oncorhynchus kisutch</i>
Common carp	<i>Cyprinus carpio</i>
Common Loon	<i>Gavia immer</i>
Common prickly ash	<i>Zanthoxylum americanum</i>
Common reed	<i>Phragmites australis</i>
Creek chub	<i>Semotilus atromaculatus</i>
Cricket frog	<i>Acris crepitans</i>
Crown-vetch	<i>Coronilla varia</i>
Curly-leaf pondweed	<i>Potamogeton crispus</i>
Dogwoods	<i>Cornus</i> spp.
Duckweed	<i>Lemna minor</i>
Dutch elm disease fungus	<i>Ophiostoma ulmi</i>
Eastern hemlock	<i>Tsuga canadensis</i>
Eastern white pine	<i>Pinus strobus</i>
Elk	<i>Cervus elaphus</i>
Elm bark beetle (native)	<i>Hylurgopinus rufipes</i>
Elm bark beetle (European)	<i>Scolytus multistriatus</i>
Elms	<i>Ulmus americana</i> , <i>U. rubra</i> , <i>U. thomasii</i>
Emerald ash borer	<i>Agrilus planipennis</i>
Eurasian buckthorns	<i>Rhamnus cathartica</i> , <i>R. frangula</i>
Eurasian honeysuckles	<i>Lonicera tatarica</i> , <i>Lonicera x bella</i> , <i>L. mackii</i> , <i>L. morrowii</i>
Eurasian water-milfoil	<i>Myriophyllum spicatum</i>
European Starling	<i>Sturnus vulgaris</i>
Fathead minnow	<i>Pimephales promelas</i>
Forest tent caterpillar	<i>Malacosoma disstria</i>
Garlic mustard	<i>Alliaria petiolata</i>

Continued on next page

Appendix 5.B, continued.

Common Name	Scientific Name
Garlic mustard biocontrol stem miners	<i>Ceutorhynchus alliariae</i> and <i>C. roberti</i>
Garlic mustard biocontrol root/crown miner	<i>Ceutorhynchus scrobicollis</i>
Gooseberries	<i>Ribes</i> spp.
Gophersnake	<i>Pituophis catenifer</i>
Gray Partridge	<i>Perdix perdix</i>
Gray ratsnake	<i>Pantherophis spiloides</i>
Gray wolf	<i>Canis lupus</i>
Green algae	<i>Cladophora</i> spp.
Gypsy moth	<i>Lymantria dispar</i>
Gypsy moth biocontrol fungus	<i>Entomophaga maimaiga</i>
Gypsy moth biocontrol virus	<i>Nucleopolyhedrosis</i>
Gypsy moth biocontrol bacteria	<i>Bacillus thuringiensis</i>
Hooded Warbler	<i>Wilsonia citrina</i>
House Sparrow	<i>Passer domesticus</i>
Hybrid poplar	<i>Populus x canadensis</i>
Indian cucumber-root	<i>Medeola virginiana</i>
Ironwood	<i>Ostrya virginiana</i>
Jack-in-the-pulpit	<i>Arisaema triphyllum</i>
Japanese barberry	<i>Berberis thunbergii</i>
Johnny darter	<i>Etheostoma nigrum</i>
Karner blue butterfly	<i>Lycaeides melissa samuelis</i>
Kentucky Warbler	<i>Oporornis formosus</i>
Largemouth bass	<i>Micropterus salmoides</i>
Leafy spurge	<i>Euphorbia esula</i>
Logperch	<i>Percina caprodes</i>
Maples	<i>Acer</i> spp.
Moose	<i>Alces alces</i>
Mountain maple	<i>Acer spicatum</i>
Multiflora rose	<i>Rosa multiflora</i>
Muskellunge	<i>Esox masquinongy</i>
Mute Swan	<i>Cygnus olor</i>
Narrow-leaved cat-tail	<i>Typha angustifolia</i>
Northern cricket frog	<i>Acris crepitans</i>
Northern red oak	<i>Quercus rubra</i>
Northern white-cedar	<i>Thuja occidentalis</i>
Norway maple	<i>Acer platanoides</i>
Oaks	<i>Quercus</i> spp.
Oriental bittersweet	<i>Celastrus orbiculata</i>
Ornate box turtle	<i>Terrapene ornata</i>
Pines	<i>Pinus</i> spp.
Prairie ring-necked snake	<i>Diadophis punctatis arnyi</i>
Prairie white-fringed orchid	<i>Platanthera leucophaea</i>
Purple loosestrife	<i>Lythrum salicaria</i>
Purple loosestrife biocontrol agents	
Leaf-feeding beetles	<i>Galerucella pusilla</i> and <i>G. californiensis</i>
Root-boring weevil	<i>Hylobius transversovittatus</i>
Flower-feeding weevil	<i>Nanophyes marmoratus</i>
Quagga mussel	<i>Dreissena bugensis</i>
Quaking aspen	<i>Populus tremuloides</i>
Rainbow smelt	<i>Osmerus mordax</i>
Rainbow trout	<i>Oncorhynchus mykiss</i>
Red maple	<i>Acer rubrum</i>
Red-osier dogwood	<i>Cornus stolonifera</i>
Reed canary grass	<i>Phalaris arundinacea</i>
Ring-necked Pheasant	<i>Phasianus colchicus</i>
River bank grape	<i>Vitis riparia</i>
Rock Dove	<i>Columba livia</i>
Ruffe	<i>Gymnocephalus cernuus</i>

Appendix 5.B, continued.

Common Name	Scientific Name
Rusty crayfish	<i>Orconectes rusticus</i>
Sea lamprey	<i>Petromyzon marinus</i>
Shorthead redhorse	<i>Moxostoma macrolepidotum</i>
Showy lady's-slipper	<i>Cypripedium reginae</i>
Sitka black-tailed deer	<i>Odocoileus hemionus sitkensis</i>
Smallmouth bass	<i>Micropterus dolomieu</i>
Southern redbelly dace	<i>Phoxinus erythrogaster</i>
Spiny water flea	<i>Bythotrephes cederstroemi</i>
Spotted knapweed	<i>Centaurea biebersteinii</i>
Spruces	<i>Picea</i> spp.
Sugar maple	<i>Acer saccharum</i>
Sumacs	<i>Rhus</i> spp.
Swainson's Thrush	<i>Catharus ustulatus</i>
Veery	<i>Catharus fuscescens</i>
Virginia creeper	<i>Parthenocissus quinquefolia</i>
Walleye	<i>Sander vitreus</i>
White ash	<i>Fraxinus americana</i>
White birch	<i>Betula papyrifera</i>
White pine blister rust	<i>Cronartium ribicola</i>
White-tailed deer	<i>Odocoileus virginianus</i>
Yellow birch	<i>Betula alleghaniensis</i>
Yellow perch	<i>Perca flavescens</i>
Zebra mussel	<i>Dreissena polymorpha</i>

^aThe common names of birds are capitalized in accordance with the checklist of the American Ornithologists Union.

Literature Cited

- Allombert, S., S. Stockton, and J.-L. Martin. 2005. A natural experiment on the impact of overabundant deer on forest invertebrates. *Conservation Biology* 19:1917–1929.
- Alverson, W.S., and D.M. Waller. 1997. Deer populations and the widespread failure of hemlock regeneration in northern forests. Pages 280–297 in W. McShea and J. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington, D.C.
- Alverson, W.S., D.M. Waller, and S.L. Solheim. 1988. Forest too deer: edge effects in northern Wisconsin. *Conservation Biology* 2:348–358.
- Anderson, R.C., E.A. Corbett, M.R. Anderson, G.A. Corbett, and T.M. Kelley. 2001. High white-tailed deer density has negative impact on tallgrass prairie forbs. *The Journal of the Torrey Botanical Society* 128:381–392.
- Anderson, R.C., D. Nelson, M.R. Anderson, and M.A. Rickey. 2005. White-tailed deer (*Odocoileus virginianus* Zimmermann) browsing effects on tallgrass prairie forbs: diversity and species abundances. *Natural Areas Journal* 25:19–25.
- Asian Carp Regional Coordinating Committee (ACRCC). 2010. 2011 Asian carp control strategy framework. December 2010. Available online at <http://www.asiancarp.us>. Accessed April 2011.
- Balگووین, C.P., and D.M. Waller. 1995. The use of *Clintonia borealis* and other indicators to gauge impacts of white-tailed deer on plant communities in northern Wisconsin, USA. *Natural Areas Journal* 15:308–318.
- Bauer-Dantoin, A., K.J. Fermanich, M.E. Zorn, and S. Wingert. 2011. Assessing levels of endocrine disrupting chemicals in groundwater associated with karst areas in northeast Wisconsin. Wisconsin Groundwater Coordinating Council, Groundwater Research and Monitoring Program, Final Report for WRI Project Number WR08R004, Madison.
- Bersing, O.S. 1966. *A century of Wisconsin deer*. Second edition. Wisconsin Department of Conservation, Game Management Division, Publication 353-66, Madison. 272 pp.
- Bioenergy Feedstock Information Network (BFIN). 2010. List of conversion factors used by the Bioenergy Feedstock Development Programs. Web page. U.S. Department of Energy, Oak Ridge National Laboratory. Available online at http://bioenergy.ornl.gov/papers/misc/energy_conv.html. Accessed June 3, 2010.
- Blossey, B., and M. Schat. 1997. Performance of *Galerucella californiensis* (Coleoptera: Chrysomelidae) on different North American populations of purple loosestrife. *Environmental Entomology* 26(2):439–445.
- Bohlen, P.J., P.M. Groffman, T.J. Fahey, M.C. Fisk, E. Suárez, D.M. Pelletier, and R.T. Fahey. 2004. Earthworm invasion of forest ecosystems: ecosystem consequences of exotic earthworm invasion of north temperate forests. *Ecosystems* 7(1):1–12.
- Bowman, D., S.E. Little, L. Lorentzen, J. Shields, M.P. Sullivan, and E.P. Carlén. 2009. Prevalence and geographic distribution of *Dirofilaria immitis*, *Borrelia burgdorferi*, *Ehrlichia canis*, and *Anaplasma phagocytophilum* in dogs in the United States: results of a national clinic-based serologic survey. *Veterinary Parasitology* 160:138–148.
- Bradley, N.L., A.C. Leopold, J. Ross, and W. Huffaker. 1999. Phenological changes reflect climate change in Wisconsin. *Proceedings of the National Academy of Sciences* 96(17):9701–9704.
- Buskirk, S.W., S.C. Forrest, M.G. Raphael, and H.J. Harlow. 1989. Winter resting site ecology of marten in the Central Rocky Mountains. *Journal of Wildlife Management* 53:191–196.
- Carstensen, M., K. DonCarlos, E. Dunbar, J. Fieberg, M.A. Larson, J. Lightfoot, C. Osmundson, and R.W. Wright. 2008. Climate change: preliminary assessment for the section of wildlife of the Minnesota Department of Natural Resources. Minnesota Department of Natural Resources, Division of Fish and Wildlife, St. Paul.
- Cates, R.L. 1990. Drinking water and groundwater quality in the lower Wisconsin River Valley. Wisconsin Department of Natural Resources, Bureau of Watershed Management, Unpublished Report. Madison. 18 pp. + maps.
- Chesters, G., J. Levy, D.P. Gustafson, H.W. Read, G.V. Simsman, D.C. Liposack, Y. Xiang. 1991. Sources and extent of atrazine contamination of groundwater at Grade A dairy farms in Dane County, Wisconsin. Wisconsin Groundwater Management Practice Monitoring Project No. 65. Final Report to the Wisconsin Department of Agriculture, Trade and Consumer Protection and the Wisconsin Department of Natural Resources, Madison. Available online at <http://digital.library.wisc.edu/1711.dl/EcoNatRes.ChestersSources>.
- Christensen, E.M. 1959. A historical view of the ranges of the white-tailed deer in northern Wisconsin forests. *American Midland Naturalist* 61:230–238.
- Cleland, D.T., P.E. Avers, W.H. McNab, M.E. Jensen, R.G. Bailey, T. King, and W.E. Russell. 1997. National hierarchical framework of ecological units. Pages 181–200 in M.S. Boyce and A. Haney, editors. 1997. *Ecosystem management: applications for sustainable forest and wildlife resources*. Yale University Press, New Haven, Connecticut.
- Collier, M.H., J.L. Vankat and M.R. Hughes. 2002. Diminished plant richness and abundance below *Lonicera maackii*, an invasive shrub. *American Midland Naturalist* 147(1):60–71.
- Côté, S.D., T.P. Rooney, J.-P. Tremblay, C. Dussault, and D.M. Waller. 2004. Ecological impacts of deer overabundance. *Annual Review of Ecology, Evolution, and Systematics* 35:113–147.
- Council of Great Lakes Governors (CGLG). 2011. Great Lakes-St. Lawrence River Basin Water Resources Compact Implementation. Web page. Available online at <http://www.cglg.org/projects/water/CompactImplementation.asp>.
- Cowell, S.E. 1992. Follow up to the Grade A dairy farm well water quality survey. Wisconsin Department of Natural Resources, Bureau of Watershed Management, PUB WR-301-92, Madison. 34 pp. + maps.
- Craven, S.C., and T.R. Van Deelen. 2008. Deer as both a cause and reflection of ecological change. Pages 273–286 in D.M. Waller and T.P. Rooney, editors. *The vanishing present: Wisconsin's changing lands, waters, and wildlife*. University of Chicago Press, Chicago. 507 pp.
- Czarapata, E.J. 2005. *Invasive plants of the upper Midwest: an illustrated guide to their identification and control*. University of Wisconsin Press, Madison. 215 pp.
- Dahlberg, B.L., and R.C. Guettinger. 1956. The white-tailed deer in Wisconsin. Wisconsin Conservation Department, Technical Bulletin 14, Madison.
- Daniel, T.C., Wietersen, R., and K.J. Fermanich. 1989. Effect of soil type on atrazine and alachlor movement through the unsaturated zone. Wisconsin Department of Natural Resources, Bureau of Water Resources Management, Final Report submitted to Wisconsin Groundwater Research Program, Wisconsin Groundwater Management Practice Monitoring Project 54, Madison.
- deCalesta, D.S. 1994. Effect of white-tailed deer on songbirds within managed forests in Pennsylvania. *Journal of Wildlife Management* 58:711–718.
- deCalesta, D.S., and S.L. Stout. 1997. Relative deer density and sustainability: a conceptual framework for integrating deer management with ecosystem management. *Wildlife Society Bulletin* 16:53–57.
- DeGraff, R.A., W.M. Healy, and R.T. Brooks. 1991. Effects of thinning and deer browsing on breeding birds in New England oak woodlands. *Forest Ecology and Management* 41:179–191.
- Environmental Protection Agency (EPA). 2000. National Water Quality Inventory 2000 Report. Environmental Protection Agency, Office of Water, EPA-841-R-02-001, Washington, D.C.
- Fargione, J., J. Hill, D. Tilman, S. Polasky, and P. Hawthorne. 2008. Land clearing and the biofuel carbon debt. *Science* 319:1235–1238.
- Fox, V.L., C.P. Buehler, C.M. Byers, and S.E. Drake. 2010. Forest composition, leaf litter, and songbird communities in oak- vs. maple-dominated forests in the eastern United States. *Forest Ecology and Management* 259:2426–2432.
- Frappier, B., R.T. Eckert, and T.D. Lee. 2003. Potential impacts of the invasive exotic shrub *Rhamnus frangula* L. (glossy buckthorn) on forests of southern New Hampshire. *Northeastern Naturalist* 10(3):277–296.
- Frappier, B., R.T. Eckert, and T.D. Lee. 2004. Experimental removal of

- the non-indigenous shrub *Rhamnus frangula* L. (glossy buckthorn): effects on native herbs and woody seedlings. *Northeastern Naturalist* 11(3):333–342.
- Frelich, L., C. Hale, S. Scheu, A. Holdsworth, L. Heneghan, P. Bohlen, and P. Reich. 2006. Earthworm invasion into previously earthworm free temperate and boreal forests. *Biological Invasions* 8:1235–1245.
- Frelich, L.E., and C.G. Lorimer. 1985. Current and predicted long-term effects of deer browsing on hemlock forests in Michigan. *Biological Conservation* 34:99–120.
- Fuller, R.J. 2001. Responses of woodland birds to increasing numbers of deer: a review of evidence and mechanisms. *Forestry* 74:289–298.
- Gill, R.M.A. 1992a. A review of damage by mammals in north temperate forests: 1. Deer. *Forestry* 65:145–169.
- Gill, R.M.A. 1992b. A review of damage by mammals in north temperate forests: 3. Impact on trees and forests. *Forestry* 65:363–388.
- Gray, R., and L. Brown. 2005. Decline of northern cricket frogs (*A. crissalis*). Pages 47–54 in M.J. Lannoo, editor. *Amphibian declines: the conservation status of U.S. amphibians*. University of California Press, Berkeley.
- Great Lakes Aquatic Nonindigenous Species Information System (GLANSIS). 2010. GLANSIS website. Available online at <http://www.glerl.noaa.gov/res/Programs/glansis/glansis.html>. Accessed September 2010.
- Grundl, T., K. Bradbury, D. Feinstein, S. Friers, and D. Hart. 2006. A combined hydrologic/geochemical investigation of groundwater conditions in the Waukesha County area, WI. University of Wisconsin Water Resources Institute, Final report submitted to Wisconsin Groundwater Research Program at completion of grant number WR03R002, Madison. Available online at <http://wri.wisc.edu/Downloads/Projects/FinalWR03R002.pdf>. Accessed August 19, 2010.
- Habeck, J.R. 1960. Winter deer activity in the white cedar swamps of northern Wisconsin. *Ecology* 41:327–333.
- Hansen, J., M. Sato, P. Kharecha, D. Beerling, R. Berner, V. Masson-Delmotte, M. Pagani, M. Raymo, D.L. Royer, and J.C. Zachos. 2008. Target atmospheric CO₂: where should humanity aim? *The Open Atmospheric Science Journal* 2:217–231.
- Harmon, M.E., W.K. Ferrell, J.F. Franklin. 1990. Effects on carbon storage of conversion of old-growth forests to young forests. *Science* 247:699–702.
- Hatch, B.K., and T.W. Bernthal. 2008. Mapping Wisconsin wetlands dominated by reed canary grass (*Phalaris arundinacea*): a landscape level assessment. Final report to the U.S. Environmental Protection Agency, Region V, Wetland Grant No. 96544501-0. Wisconsin Department of Natural Resources, PUB WT-900-2008, Madison.
- Hay, R. 1998. Blanchard's cricket frogs in Wisconsin: a status report. Pages 79–82 in M. J. Lannoo, editor. *The status and conservation of midwestern amphibians*. University of Iowa Press, Iowa City.
- Heller, N., and E. Zavaleta. 2009. Biodiversity management in the face of climate change: a review of 22 years of recommendations. *Biological Conservation* 142:14–32.
- Herrick, S., J. Kovach, E. Padley, C. Wagner, and D. Zastrow. 2009. Wisconsin's forestland woody biomass harvesting guidelines: field manual for loggers, landowners, and land managers. Wisconsin Department of Natural Resources Division of Forestry and Wisconsin Council on Forestry, PUB-FR-435-2009, Madison.
- Holdsworth A.R., L.E. Frelich, and P.B. Reich. 2007. Effects of earthworm invasion on plant species richness in northern hardwood forests. *Conservation Biology* 21(4):997–1008.
- Hotchkiss, S., and D. Mladenoff. 2007. Climate change and the Wisconsin environment: identifying likely changes and key vulnerabilities in Wisconsin's terrestrial habitats and bird and mammal species. Wildlife Restoration (Pittman Robertson) Program Pre-Proposal. Wisconsin Department of Natural Resources, Madison. 2 pp.
- Hull, S., J. Arntzen, C. Bleser, A. Crossley, R. Jackson, E. Lobner, L. Paine, G. Radloff, D. Sample, J. Vandenbrook, S. Ventura, S. Walling, J. Widholm, and C. Williams. 2011. Wisconsin sustainable planting and harvest guidelines for nonforest biomass. Wisconsin Department of Natural Resources, University of Wisconsin-Madison, and Wisconsin Department of Agriculture, Trade, and Consumer Protection, Madison. Available online at <http://datcp.wi.gov/uploads/About/pdf/WI-NFB-GuidelinesFinalOct2011.pdf>. Accessed May 2012.
- Hutchinson, T. E., and J. L. Vankat. 1997. Invasibility and effects of Amur honeysuckle in southwestern Ohio forests. *Conservation Biology* 11:1117–1124.
- Intergovernmental Panel on Climate Change (IPCC). 2007. Climate change 2007 synthesis report. Contribution of working groups I, II and III to the fourth assessment report of the Intergovernmental Panel on Climate Change, Geneva, Switzerland. Available online at http://www.ipcc.ch/publications_and_data/ar4/syr/en/contents.html. Accessed September 2010.
- Invasive Plants Association of Wisconsin (IPAW). 2003. Plants out of place. Newsletter, Issue 4. Available online at <http://ipaw.org/newsletters/issue4.pdf>. Accessed September 2010.
- Invasive Plants Association of Wisconsin (IPAW). 2010. Brochure. Available online at <http://ipaw.org/brochure.pdf>. Accessed September 2010.
- Kearns, S.K. 2008. Nonnative terrestrial species invasions. Pages 439–452 in D.M. Waller and T.P. Rooney, editors. *The vanishing present: Wisconsin's changing lands, waters, and wildlife*. University of Chicago Press, Chicago. 507 pp.
- Kilpatrick, H.J. and A.M. LaBonte. 2007. Managing urban deer: a guide for residents and communities. Second edition. Connecticut Department of Environmental Protection, Bureau of Natural Resources, Wildlife Division, Hartford. 36 pp.
- Kramasz, K., and G. Breese. 2010. A delicate balance where land meets water: guidelines on building and renovating waterfront property have been updated for the first time in 40 years. *Wisconsin Natural Resources Magazine* April 2010.
- Kucharik, C.J., S.P. Serbin, E.J. Hopkins, S. Vavrus, and M.M. Motew. 2010. Patterns of climate change across Wisconsin from 1950 to 2006. *Physical Geography* 31:1–28.
- LeMasters, G., and J. Baldock. 1997. A survey of atrazine in Wisconsin groundwater. Wisconsin Department of Agriculture, Trade and Consumer Protection, Division of Agricultural Resource Management, Final Report, Madison.
- LeMasters, G., and D.J. Doyle. 1989. Grade A dairy farm well water quality survey. Wisconsin Department of Agriculture, Trade and Consumer Protection and Wisconsin Agricultural Statistics Service, Madison. Available online at http://datcp.wi.gov/uploads/Environment/pdf/Grade_A_Survey.pdf.
- Lowry, C.S., and M.P. Anderson. 2003. An assessment of aquifer storage recovery using ground water flow models. *Ground Water* 44(5):661–667.
- Lyons, J.D. 2007. Predicted effects of water temperature increases on the distribution of warmwater fishes in Wisconsin streams and rivers. Abstract from presentation at 68th Midwest Fish and Wildlife Conference, December 10–11, 2007, Madison, Wisconsin. Available online at <http://wiatri.net/projects/mfwcsearch/viewSession.cfm?SessionID=WS-05b>. Accessed May 2012.
- Manomet Center for Conservation Sciences (MCCS). 2010. Massachusetts biomass sustainability and carbon policy study. Prepared for Commonwealth of Massachusetts, Department of Energy Resources, Natural Capital Initiative Report NCI-2010-03, Brunswick, Maine.
- McCabe, T.R. and R.E. McCabe. 1997. Recounting whitetails past. Pages 11–26 in W. J. McShea, H. B. Underwood, and J. H. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington D.C.
- McCaffery, K.R. 1995. History of deer in northern Wisconsin. Pages 109–114 in G. Mroz and J. Martin, editors. *Hemlock ecology and management: proceedings of a regional conference on ecology and management of eastern hemlock*. September 27–28, 1995, Iron Mountain, Michigan.
- McCullough, D.G., and J.E. Zablutny. 2002. Directory of exotic forest insect and disease pests. Michigan State University Extension, Bulletin E-2811, East Lansing. 42 pp.
- McKinney, M.L., and J.L. Lockwood. 1999. Biotic homogenization: a few winners replacing many losers in the next mass extinction. *Trends in Ecology & Evolution* 14:450–453.
- McShea, W.J., and J.H. Rappole. 2000. Managing the abundance and diversity of breeding bird populations through manipulation of deer populations. *Conservation Biology* 14:1161–1170.

- McSweeney, K., K. Fermanich, B. Lowery, and S. Grant. 1991. Atrazine leaching at a field site in the Lower Wisconsin River Valley. *Proceedings of the Fertilizer, Agrilime and Pest Management Conference* 30:129–137.
- Miller, S.G., S.P. Bratton, and J. Hadidian. 1992. Impacts of white-tailed deer on endangered and threatened vascular plants. *Natural Areas Journal* 12:67–74.
- Mitro, M.G., J.D. Lyons, and J.S. Stewart. 2007. Climate change, trout ecology and the future of inland trout management in Wisconsin. Abstract from presentation at 68th Midwest Fish and Wildlife Conference, December 10–11, 2007, Madison, Wisconsin. Available online at <http://wiatri.net/projects/mfwcsearch/viewSession.cfm?SessionID=WS-05b>. Accessed May 2012.
- Mladenoff, D.J. 1987. Dynamics of nitrogen mineralization and nitrification in hemlock and hardwood treefall gaps. *Ecology* 68:1171–1180.
- Myers, J.A., M. Vellend, S. Gardescu, and P.L. Marks. 2004. Seed dispersal by white-tailed deer: implications for long-distance dispersal, invasion, and migration of plants in eastern North America. *Oecologia* 139:35–44.
- North American Bird Conservation Initiative (NABCI) U.S. Committee. 2010. The state of the birds 2010 report on climate change, United States of America. U.S. Department of the Interior, Washington, D.C. Available online at <http://www.stateofthebirds.org/>. Accessed April 2010.
- Nuzzo, V.A., J.C. Maerz, and B. Blossey. 2009. Earthworm invasion as the driving force behind plant invasion and community change in north-eastern North American Forests. *Conservation Biology* 23(4):966–974.
- Paine, L.K., T.L. Peterson, D.J. Undersander, K.C. Rineer, G.A. Bartelt, S.A. Temple, D.W. Sample, and R.M. Klemme. 1996. Some ecological and socio-economic considerations for biomass energy crop production. *Biomass and Bioenergy* 10:231–242.
- Pastor, J., J.D. Aber, C.A. McClaugherty, and J.M. Melillo. 1984. Above ground production and N and P cycling along a nitrogen mineralization gradient on Blackhawk Island, Wisconsin. *Ecology* 65:256–268.
- Pastor, J.R., and D.J. Mladenoff. 1992. The southern boreal-northern hardwood forest border. Pages 216–240 in H. H. Shugart, R. Leemans, and G. B. Bonan, editors. *A system analysis of the global boreal forest*. Cambridge University Press, Cambridge, UK.
- Pastor, J., R.J. Naiman, and P.F. McInnes. 1988. Moose, microbes, and the boreal forest. *Bioscience* 38:770–777.
- Pietz, P.J., and D.A. Granfors. 2000. White-tailed deer (*Odocoileus virginianus*) predation on grassland songbird nestlings. *American Midland Naturalist* 144(2):419–422.
- Pillsbury, R.W., R.L. Lowe, Y.D. Pan, and J.L. Greenwood. 2002. Changes in the benthic algal community and nutrient limitation in Saginaw Bay, Lake Huron, during the invasion of the zebra mussel (*Dreissena polymorpha*). *Journal of the North American Benthological Society* 21:238–252.
- Pimentel, D. 2003. Ethanol fuels: energy balance, economics, and environmental impacts are negative. *Natural Resources Research* 12:127–134.
- Riewe, T. Undated. Wisconsin: Geologic Solution for Private Wells in Outagamie and Winnebago Counties. U.S. Environmental Protection Agency, Arsenic in drinking water: compliance success stories, Washington, D.C. Available online at <http://water.epa.gov/lawsregs/rulesregs/sdwa/arsenic/Compliance.cfm>. Accessed March 30, 2012.
- Rogers, L.L., J.J. Moaty, and D. Dawson. 1981. Foods of white-tailed deer in the Upper Great Lakes Region—a review. U.S. Forest Service, North Central Forest Experimental Station, General Technical Report NC-65, St. Paul, Minnesota.
- Rooney, T.P. 2001. Deer impacts on forest ecosystems: a North American perspective. *Forestry* 74:201–208.
- Rooney, T.P. 2009. High white-tailed deer densities benefit graminoids and contribute to biotic homogenization of forest ground-layer vegetation. *Plant Ecology* 202:103–111.
- Rooney, T.P., S.L. Solheim, and D.M. Waller. 2002. Factors influencing the regeneration of northern white cedar in lowland forests of the Upper Great Lakes region, USA. *Forest Ecology and Management* 163:119–130.
- Rooney, T.P., and D.M. Waller. 2003. Direct and indirect effects of white-tailed deer in forest ecosystems. *Forest Ecology and Management* 181(2003):165–176.
- Rooney, T., S. Wiegmann, D. Rogers, and D. Waller. 2004. Biotic impoverishment and homogenization in unfragmented forest communities. *Conservation Biology* 18(3):787–798.
- Roth, A.M., D.W. Sample, C.A. Ribic, L. Paine, D.J. Undersander, and G.A. Bartelt. 2005. Grassland bird response to harvesting switchgrass as a biomass energy crop. *Biomass and Bioenergy* 28:490–498.
- Russell, F.L., D.B. Zippin, and N.L. Fowler. 2001. Effects of white-tailed deer (*Odocoileus virginianus*) on plants, plant populations, and communities: a review. *American Midland Naturalist* 146:1–26.
- Schorger, A.W. 1953. The white-tailed deer in early Wisconsin. *Transactions of the Wisconsin Academy of Sciences, Arts and Letters* 42:197–247.
- Searchinger T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T.-H. Yu. 2008. Use of U.S. croplands for biofuels increases greenhouse gases through emissions from land-use change. *Science* 319:1238–1240).
- Secchi, S., and B.A. Babcock. 2007. Impact of high corn prices on Conservation Reserve Program acreage. *Iowa Ag Review* 13(2):4–7.
- Shapouri, H., J.A. Duffield, and M. Wang. 2002. The energy balance of corn ethanol: an update. U.S. Department of Agriculture, Office of Energy Policy and New Uses, Agricultural Economics. Report No. 813, Washington, D.C.
- Stankovich, W.S. 2004. The interaction of two nuisance species in Lake Michigan: *Cladophora glomerata* and *Dreissena polymorpha*. Proceedings of a workshop held at the Great Lakes WATER Institute, University of Wisconsin-Milwaukee, December 8, 2004. Available online at http://www.glwi.uwm.edu/research/aquaticceology/cladophora/pdf_workshop_proceedings/Stankovich%2031%20to%2036.pdf. Accessed January 2013.
- Stinson, K.A., S.A. Campbell, J.R. Powell, B.E. Wolfe, R.M. Callaway, G.C. Thelen, S.G. Hallett, D. Prati, and J.N. Klironomos. 2006. Invasive plant suppresses the growth of native tree seedlings by disrupting below-ground mutualisms. *PLoS Biology* 4(5):e140.
- Stoll, R. 1992. Arsenic as a naturally elevated parameter in water supply wells in eastern Winnebago and Outagamie Counties. Wisconsin Department of Natural Resources, Bureau of Watershed Management, Final Report to DNR, Madison.
- Stoll, R. 1994. The further incidence of native arsenic in eastern Wisconsin water supply wells: Marinette, Oconto, Shawano and Brown Counties. Wisconsin Department of Natural Resources, Bureau of Watershed Management, Final Report to DNR, Madison.
- Swift, E. 1946. A history of Wisconsin deer. Wisconsin Conservation Department, Publication 323, Madison.
- Tilghman, N.G. 1989. Impacts of white-tailed deer on forest regeneration in northwestern Pennsylvania. *Journal of Wildlife Management* 53:524–532.
- Tremblay, J.P. 2005. Ecological impacts of deer overabundance on temperate and boreal forests. Pages 51–84 in *Proceedings of the Michigan Society of American Foresters: forests & wildlife – striving for balance*. June 9–10, 2005, St. Ignace, Michigan.
- University of Wisconsin Extension (UWEX) Center for Land Use Education. 2007. Wisconsin land use megatrends: recreation. University of Wisconsin Extension, Stevens Point. 8 pp.
- University of Wisconsin Extension (UWEX) Center for Land Use Education. 2008. Wisconsin land use megatrends: energy. University of Wisconsin Extension, Stevens Point. 12 pp.
- University of Wisconsin Extension (UWEX) Center for Land Use Education. 2009. Wisconsin land use megatrends: housing. University of Wisconsin Extension, Stevens Point. 8 pp.
- U.S. Forest Service (USFS). 1988. Final environmental impact statement – land and resource management plan, Nicolet National Forest. U.S. Forest Service, Rhinelander, Wisconsin.
- U.S. Forest Service (USFS), Michigan State University, Purdue University, and Ohio State University. 2010. Emerald ash borer: Michigan Information. Web page. Available online at <http://www.emeraldashborer.info/michiganinfo.cfm>. Accessed September 2010.
- Vander Zanden M.J., and J.T. Maxted. 2008. Forecasting species invasions in Wisconsin lakes and streams. Pages 423–438 in D.M. Waller and T.P. Rooney, editors. *The vanishing present: Wisconsin's changing lands, waters, and wildlife*. University of Chicago Press. Chicago. 507 pp.
- VanderZouwen, W.J., and D.K. Warnke. 1995. Wisconsin deer population

- goals and harvest management: environmental assessment. Wisconsin Department of Natural Resources, Madison. 327 pp.
- Waller, D.M., W.S. Alverson, and S.L. Solheim. 1996. Local and regional factors influencing the regeneration of eastern hemlock. Pages 73–90 in G. Mroz and J. Martin, editors. *Hemlock ecology and management: proceedings of a regional conference on ecology and management of eastern hemlock*. September 27–28, 1995, Iron Mountain, Michigan.
- Waller, D.M., S. Johnson, R. Collins, and E. Williams. 2009. Threats posed by ungulate herbivory to forest structure and plant diversity in the upper Great Lakes region with a review of methods to assess those threats. National Park Service, Natural Resource Report NPS/GLKN/NRR–2009/102, Fort Collins, Colorado.
- Witersen, R.C., T.C. Daniel, K.J. Fermanich, B.D. Girard, K. McSweeney, and B. Lowery. 1993. Atrazine, alachlor, and metolachlor mobility through two sandy Wisconsin soils. *Journal of Environmental Quality* 22:811–818.
- Wilcove, D.S., D. Rothstein, J. Dubow, A. Phillips, and E. Loso. 1998. Quantifying threats to imperiled species in the United States. *Bioscience* 48: 607–615.
- Willyard, C.J., and S.M. Tikalsky. 2006. Bioenergy in Wisconsin: the potential supply of forest biomass and its relationship to biodiversity. State of Wisconsin, Department of Administration, Division of Energy, Environmental Research Program, Final Report, Madison. Available online at http://www.focusonenergy.com/files/Document_Management_System/Environmental_Research/tikalskyfishmurcury_report.pdf. Accessed September 28, 2007.
- Wisconsin Council on Forestry. 2005. Deer impacts on forest ecology and management: 2005 reforestation (artificial regeneration) survey. Web page. Available online at <http://council.wisconsinforestry.org/deer/deer-survey.php>. Accessed April 2010.
- Wisconsin Council on Forestry. 2006a. Deer impacts on forest ecology and management: 2006 natural oak regeneration survey. Web page. Available online at <http://council.wisconsinforestry.org/deer/deerregen.php>. Accessed April 2010.
- Wisconsin Council on Forestry. 2006b. Deer impacts on forest ecology and management: 2006 plantation (artificial regeneration) assessment. Web page. Available online at <http://council.wisconsinforestry.org/deer/deer-assess.php>. Accessed April 2010.
- Wisconsin Council on Forestry. 2009. Invasive species best management practices. Web page. Available online at <http://council.wisconsinforestry.org/invasives>. Accessed April 2010.
- Wisconsin Department of Health Services (DHS). 2010. Lyme disease: data and statistics. Web page. Available online at <http://www.dhs.wisconsin.gov/communicable/Tickborne/Lyme/DataandStatistics.htm>. Accessed September 2010.
- Wisconsin Department of Natural Resources (DNR). 1998. Wisconsin's deer management program: the issues involved in decision-making. Second edition. Wisconsin Department of Natural Resources, PUB-SS-931-98, Madison.
- Wisconsin Department of Natural Resources (DNR). 2001. Management workbook for white-tailed deer. Second edition. Wisconsin Department of Natural Resources, Bureaus of Wildlife Management and Integrated Science Services, PUB-WM-355-2001, Madison. 170 pp.
- Wisconsin Department of Natural Resources (DNR). 2005. Wisconsin's strategy for wildlife species of greatest conservation need. Wisconsin Department of Natural Resources, Wisconsin Wildlife Action Plan, PUB-ER-641 2005, Madison. Available online at <http://dnr.wi.gov/>, keyword "Wildlife Action Plan."
- Wisconsin Department of Natural Resources (DNR). 2008. Reversing the loss: a strategy to protect, restore and explore Wisconsin wetlands. Wisconsin Department of Natural Resources, PUB WT-893 2008, Madison.
- Wisconsin Department of Natural Resources (DNR). 2009a. Administrative Code NR 40: invasive species identification, classification, and control. Wisconsin Legislative Reference Bureau, Wisconsin Administrative Register, Madison. Available online at <http://www.legis.state.wi.us/rsb/code/nr/nr040.pdf>. Accessed April 2010.
- Wisconsin Department of Natural Resources (DNR). 2009b. 2007–08 report to the Legislature on aquatic invasive species. Wisconsin Department of Natural Resources, Madison. Available online at <http://dnr.wi.gov/topic/invasives/documents/2007-08reporttothelegislatureonaquaticinvasivespecies-wdnr.pdf>. Accessed January 2009.
- Wisconsin Department of Natural Resources (DNR). 2009c. Wisconsin's Great Lakes strategy: restoring and protecting our Great Lakes. Wisconsin Department of Natural Resources, Office of the Great Lakes, PUB-WT-907-2009, Madison. Available online at <http://dnr.wi.gov/topic/greatlakes/documents/strategybrochure.pdf>.
- Wisconsin Department of Natural Resources (DNR). 2010a. A strategic plan to manage invasives. *Wisconsin Natural Resources Magazine* April 2010:24–27. Available online at <http://dnr.wi.gov/wnrmag/2010/04/invasives.htm>. Accessed April 2010.
- Wisconsin Department of Natural Resources (DNR). 2010b. Ballast Water Discharge General Permit. Web page. Available online at http://dnr.wi.gov/news/mediakits/mk_ballast.asp.
- Wisconsin Department of Natural Resources (DNR). 2010c. Wildlife Damage Abatement and Claims Program. Web page. Available online at <http://dnr.wi.gov/aid/wdacp.html>. Accessed September 2010.
- Wisconsin Department of Natural Resources (DNR). 2010d. Wisconsin's forestry best management practices for water quality: field manual for loggers, landowners, and land managers. Wisconsin Department of Natural Resources, Division of Forestry, PUB FR-093 2010, Madison. Available online at <http://dnr.wi.gov/topic/forestmanagement/documents/pub/fr-093.pdf>.
- Wisconsin Department of Natural Resources (DNR). 2011. A water quality trading framework for Wisconsin: a report to the Natural Resources Board. July 1, 2011. Wisconsin Department of Natural Resources, Madison. Available online at <http://fyi.uwex.edu/wqtrading/files/2011/07/WQT-Framework-Final.pdf>. Accessed March 30, 2012.
- Wisconsin Department of Natural Resources (DNR). 2012a. Consult a professional. Web page. Available online at <http://dnr.wi.gov/>, keywords "wetland professional." Accessed March 2013.
- Wisconsin Department of Natural Resources (DNR). 2012b. Gateway to basins, watersheds. Web page. Wisconsin Department of Natural Resources, Madison. Available online at <http://dnr.wi.gov>, keywords "gateway to basins."
- Wisconsin Department of Natural Resources (DNR). 2012c. Silica (frac) sand mining in Wisconsin. Web page. Wisconsin Department of Natural Resources, Madison. Available online at <http://dnr.wi.gov/>, keywords "silica sand mining."
- Wisconsin Department of Natural Resources (DNR). 2012d. Wetlands benefit people and nature. Web page. Available online at <http://dnr.wi.gov/>, keyword "wetlands." Accessed March 2013.
- Wisconsin Department of Natural Resources (DNR). 2013. Beech bark disease. Web page. Available online at <http://dnr.wi.gov/topic/foresthealth/beechnbarkdisease.html>.
- Wisconsin Department of Transportation (DOT). 2010. Motor vehicle-deer crashes in 2010. Wisconsin Department of Transportation safety and consumer protection web page. Available online at <http://www.dot.wisconsin.gov/safety/motorist/crashfacts/docs/deerfacts.pdf>. Accessed April 2010.
- Wisconsin Groundwater Coordinating Council (WGCC). 2012. Arsenic monitoring and research in northeastern Wisconsin. Supplement to Wisconsin Groundwater Coordinating Council fiscal year 2012 Report to the Legislature. Available online at <http://dnr.wi.gov/topic/groundwater/documents/GCC/Benefits/ArsenicResearch.pdf>.
- Wisconsin Initiative on Climate Change Impacts (WICCI). 2010a. Wildlife Working Group Report. University of Wisconsin-Madison Nelson Institute for Environmental Studies and the Wisconsin Department of Natural Resources, Madison.
- Wisconsin Initiative on Climate Change Impacts (WICCI). 2010b. Wisconsin initiative on climate change impacts. Website. Available at <http://www.wicci.wisc.edu/>. Accessed May 2010.
- Woods, K.D. 1993. Effects of invasion by *Lonicera tartarica* L. on herbs and tree seedlings in four New England forests. *American Midland Naturalist* 130(1):62–74.

Additional References

- Anderson, R.C., and A.J. Katz. 1993. Recovery of browse-sensitive tree species following release from white-tailed deer (*Odocoileus virginianus* Zimmerman) browsing pressure. *Biological Conservation* 63:203–208.
- Anderson, R.C., and O.L. Loucks. 1979. White-tail deer (*Odocoileus virginianus*) influence on structure and composition of *Tsuga canadensis* forests. *Journal of Applied Ecology* 16:855–861.
- Augustine, D.J., and D. deCalesta. 2003. Defining deer overabundance and threats to forest communities: from individual plants to landscape structure. *Ecoscience* 10(4):472–486.
- Augustine, D.J., and L.E. Frelich. 1998. Effects of white-tailed deer on populations of an understory forb in fragmented deciduous forests. *Conservation Biology* 12:995–1004.
- Berthel, T.W., and K.G. Willis. 2004. Using Landsat 7 imagery to map invasive reed canary grass (*Phalaris arundinacea*): a landscape level wetland monitoring methodology. Final Report to the U.S. Environmental Protection Agency, Region V, Wisconsin Department of Natural Resources, PUB SS-992-2004, Madison.
- Didier, K.A., and W.F. Porter. 2003. Relating spatial patterns of sugar maple reproductive success and relative deer density in northern New York state. *Forest Ecology and Management* 181:253–266.
- Eschtruth, A.K., and J.J. Battles. 2009. Acceleration of exotic plant invasion in a forested ecosystem by a generalist herbivore. *Conservation Biology* 23(2):388–99.
- Frye, R. 2008. *Deer wars: science, tradition, and the battle over managing whitetails in Pennsylvania*. Penn State University Press, University Park, Pennsylvania.
- Gopalakrishnan, G., M. Cristina Negri, M. Wang, M. Wu, S.W. Snyder, and L. Lafreniere. 2009. Biofuels, land, and water: a systems approach to sustainability. *Environmental Science & Technology* 43:6094–6100.
- Hale, C.M., L.E. Frelich, and P.B. Reich. 2005. Exotic European earthworm invasion dynamics in northern hardwood forests of Minnesota, USA. *Ecological Applications* 15:848–860.
- Harris, V. 2005. *Cladophora* confounds coastal communities – public perceptions and management dilemmas. Pages 5–13 in Proceedings of workshop on *Cladophora* research and management in the Great Lakes. University of Wisconsin-Milwaukee Great Lakes Water Institute, Special Report No. 2005-01, Milwaukee.
- Heneghan, L., F. Fatemi, L. Umek, K. Grady, K. Fagen and M. Workman. 2006. The invasive shrub European buckthorn (*Rhamnus cathartica* L.) alters soil properties in midwestern U.S. woodlands. *Applied Soil Ecology* 32:142–148.
- Heneghan, L., C. Rauschenberg, F. Fatemi, and M. Workman. 2004. European buckthorn (*Rhamnus cathartica*) and its effects on some ecosystem properties in an urban woodland. *Ecological Restoration* 22(4):275–280.
- Horsley, S.B., S.L. Stout, and D.S. DeCalesta. 2003. White-tailed deer impact on the vegetation dynamics of a northern hardwood forest. *Ecological Applications* 13:98–118.
- Huntley, N. 1991. Herbivores and the dynamics of communities and ecosystems. *Annual Review of Ecology and Systematics* 22:477–503.
- Kraft, L.S., T.R. Crow, D.S. Buckley, E.Z. Nauertz, and J.C. Zasada. 2004. Effects of harvesting and deer browsing on attributes of understory plants in northern hardwood forests, Upper Michigan, USA. *Forest Ecology & Management* 199:219–230.
- Lenarz, M.S. 2009. A review of the ecology of *Parelaphostrongylus tenuis* in relation to deer and moose in North America. Pages 70–75 in M.W. DonCarlos, R.O. Kimmel, J.S. Lawrence, and M.S. Lenarz, editors. *Summaries of wildlife research findings*. Minnesota Department of Natural Resources, Division of Fish and Wildlife, St. Paul.
- Leopold, A. 1943a. Deer irruptions. *Transactions of the Wisconsin Academy of Sciences, Arts, and Letters* 35:351–366. Available online at <http://digital.library.wisc.edu/1711.dl/WI.WT1943>.
- Leopold, A. 1943b. The excess deer problem. *Audubon* 45:156–157.
- Leopold, A. 1946. The deer dilemma. *Wisconsin Conservation Bulletin* 11:3–5.
- Marquis, D.A. 1981. Effects of deer browsing on timber production in Allegheny hardwood forests of northwestern Pennsylvania. U.S. Forest Service, Northeastern Forest Research Station, Research Paper NE-475, Broomall, Pennsylvania.
- Marquis, D.A., and T.J. Grisez. 1978. The effect of deer exclosures on the recovery of vegetation in failed clearcuts on the Allegheny plateau. U.S. Forest Service, Northeastern Forest Research Station, Research Note NE-270, Broomall, Pennsylvania.
- McGraw, J.B., and M.A. Furedi. 2005. Deer browsing and population viability of a forest understory plant. *Science* 307:920–922.
- McShea, W.J., H.B. Underwood, and J.H. Rappole. 1997. Deer management and the concept of overabundance. Pages 1–10 in W.J. McShea, H.B. Underwood, and J.H. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington D.C.
- Mladenoff, D.J., and F. Stearns. 1993. Eastern hemlock regeneration and deer browsing in the northern great lakes region: a re-examination and model simulation. *Conservation Biology* 7:889–900.
- Mudrak, E.L., S.E. Johnson, and D.M. Waller. 2009. Forty-seven year changes in vegetation at the Apostle Islands: effects of deer on the forest understory. *Natural Areas Journal* 29:167–176.
- Reo, N.J., and J.W. Karl. 2010. Tribal and state ecosystem management regimes influence forest regeneration. *Forest Ecology and Management* 260:734–743.
- Ricciardi, A. 2001. Facilitative interactions among the aquatic invaders: is an “invasional meltdown” occurring in the Great Lakes? *Canadian Journal of Fisheries and Aquatic Sciences* 58(2):2513–2525.
- Sinclair, A.R.E. 1997. Carrying capacity and the overabundance of deer: a framework for management. Pages 380–394 in W.J. McShea, H.B. Underwood, and J.H. Rappole, editors. *The science of overabundance: deer ecology and population management*. Smithsonian Institution Press, Washington D.C.
- U.S. Energy Information Administration. 2012. Wisconsin state profile and energy estimates. Web page. Available online at <http://www.eia.gov/state/state-energy-profiles.cfm?sid=WI>. Accessed June 3, 2010.
- U.S. Forest Service. 2010. Forest Inventory and Analysis National Program, Forest Inventory Data Online web page. Available online at <http://fia-tools.fs.fed.us/fido/index.html>. Accessed June 3, 2010.
- Van Deelen, T.R. 1999. Deer-cedar interactions during a period of mild winters: implications for conservation of conifer swamp deer yards in the Great Lakes region. *Natural Areas Journal* 19:263–274.
- Vellend, M. 2002. A pest and an invader: white-tailed deer (*Odocoileus virginianus* Zimm.) as a seed dispersal agent for honeysuckle shrubs (*Lonicera* L.). *Natural Areas Journal* 22:230–234.
- Waller, D.M. 2002. White-tailed deer impacts in continental North America and the challenge of managing a hyperabundant herbivore. Pages 135–147 in A.J. Gaston, T.E. Golumbia, J.-L. Martin, and S.T. Sharpe, editors. *Lessons from the islands: introduced species and what they tell us about how ecosystems work*. Canadian Wildlife Service, Queen Charlotte City, Queen Charlotte Islands, British Columbia.
- Waller, D.M., and W.S. Alverson. 1997. The white-tailed deer: a keystone herbivore. *Wildlife Society Bulletin* 25:217–226.
- Warren, R.J. 1991. Ecological justification for controlling deer populations in Eastern National Parks. *Transactions of the North American Wildlife and Natural Resources Conference* 56:56–66.
- Warren, R.J. 1997. Special issue: deer overabundance. *Wildlife Society Bulletin* 25:209–577.
- Wiegmann, S.M. 2006. Fifty years of change in northern forest understory plant communities of the upper Great Lakes. Ph.D. Dissertation, University of Wisconsin-Madison, Madison.
- Wisconsin Department of Natural Resources. 2006. The 2005–2010 Wisconsin Statewide Comprehensive Outdoor Recreation Plan (SCORP). Wisconsin Department of Natural Resources, PUB PR-026-2006, Madison.

Wisconsin Department of Natural Resources. 2010a. *A field guide to terrestrial invasive plants in Wisconsin*. Wisconsin Department of Natural Resources, Bureau of Endangered Resources and Division of Forestry, PUB-FR-436-2010, Madison.

Wisconsin Department of Natural Resources. 2010b. Common terrestrial invasive plants in Wisconsin. Wisconsin Department of Natural Resources, Bureau of Endangered Resources, PUB FR-456-2010, Madison. Available online at [http://dnr.wi.gov/topic/forestmanagement/doc-](http://dnr.wi.gov/topic/forestmanagement/documents/pub/fr-456.pdf)

[uments/pub/fr-456.pdf](http://dnr.wi.gov/topic/forestmanagement/documents/pub/fr-456.pdf). Accessed April 2010.

Wisconsin Department of Natural Resources. 2010c. Water quality report to Congress. Wisconsin Department of Natural Resources, PUB WT-924-2010, Madison.

Wisconsin Groundwater Coordinating Council (WGCC). 2012. Groundwater: Wisconsin's buried treasure — 2009. Report to the Legislature. Available online at <http://dnr.wi.gov/topic/groundwater/documents/GCC/Report/gccReport2012.pdf>.